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NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

LUNAR LIFTING IMPLEMENT

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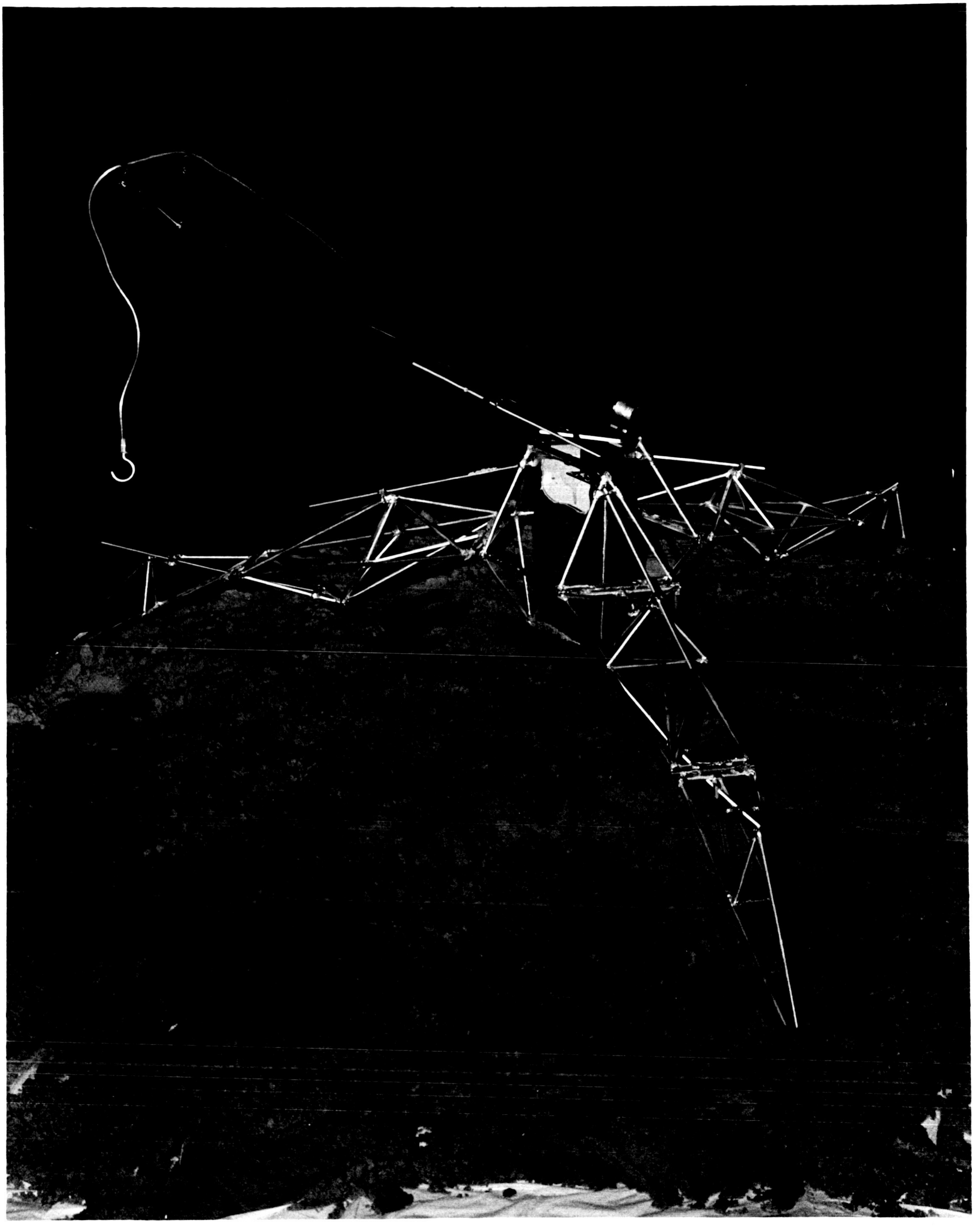

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ABSTRACT

A conceptual design for a lunar lifting implement for the SKITTER is presented in this paper. This lifter consists of a boom mounted on a triangular platform that connects to the SKITTER base at its three vertices. The boom is controlled by two mechanical linear actuators which attach to the bottom of the boom and two of the base's vertices.

Lifting operations are performed by remote control, and the lifter is equipped with video cameras and lights to facilitate day/night and remote operation. Actual lifting is performed by a hoist system that is attached through the boom structure to the platform. The hoist incorporates a block and tackle at the end of the boom for stability of the load and Kevlar rope for weight conservation and strength.

Power for the entire lifter is supplied by a hydrogen-oxygen fuel cell. Since the SKITTER will be using other implements at different times, the lifter will be stored on an A-frame when it is not being used. The lifting implement should be the first piece of equipment deployed to the lunar surface and could probably be attached to the SKITTER and landed on the lunar surface as one unit.

The lifter had to be designed under the constraints of the lunar environment, so it could not look and work exactly like a crane would on earth. Weight of the lifter was the most important design criteria since the cost of transporting it to the lunar surface is directly related to its weight.

SPECIFICATIONS: LUNAR LIFTING IMPLEMENT

GENERAL DIMENSIONS

Total weight	750.17 kg
Boom length	10.20 m
Boom width	.75 m

BOOM PERFORMANCE

Horizontal max. reach	6.29 m @ 51 degrees
(from rear of base)	9.58 m @ 20 degrees
Vertical max. lift (from base)	8.00 m @ 51 degrees
Swing angle	60 degrees (30 deg. each side)
Positioning rate, max.	47.78 cm/min
Max. lifting load	4000 lbs @ 51 degrees, 0 deg. swing

HOIST PERFORMANCE

Lifting rate (variable)	2 tons @ 8 ft/min
Drum capacity	12 m
Cable	Kevlar, 12.7 mm dia. 10,546 kg breaking strength

ACTUATOR PERFORMANCE

Capacity	30,000 lbs
Max. collar extend/retract	12.50 cm
Power	3/4 Hp DC motor

POWER SYSTEM

Avg. power output	3.86 KW
Peak power output	12.00 KW
Max. continous operating time	10 hrs
Fuel consumption rate	1.25 g/sec

PROBLEM STATEMENT

BACKGROUND

As a major objective for the space program, NASA has proposed that a manned facility be placed on the moon as a scientific research center and refueling station for further space exploration. In order to have a fully operable base, which will support fuel mining and scientific activities, a small first phase will be constructed during the early part of the next century.

This lunar base will be a modular design, and in order to construct the first phase, a lifting device is needed to lift modules, equipment, and various supplies from the lunar transport vehicles. After the initial construction is completed this device may also be used in mining operations and further construction. Some type of lifing implement which will attach to the skitter is best suited for these functions.

The lunar lifting implement (or lifter) will load and/or unload lunar modules, equipment, and various supplies from the lunar transport vehicles at the lunar surface. This lifter will also aid in the construction of the first phase of the lunar base by lifting and placing modules and materials.

PERFORMANCE OBJECTIVES

One of the first pieces of equiment deployed to the lunar surface will be the lifter, which will then be required to operate during the first ten years of lunar base operations. In order to function properly, the lifter must meet certain objectives. It must be able to lift a variety of loads and then place the loads onto transporters. Special techniques will be devised to lift loads that exceed design specifications. The lifter will also be expected to operate during lunar days and nights.

An operator will control the lifter from a remote position which may be in view of the skitter or back on earth. Cameras will be mounted on the lifter to facilitate controlling it. After the lifter has been used for an operation, it will be removed from the skitter and stored until it is needed again. An independent power supply must also be part of the lifter, and it must be both statically and dynamically stable.

Specific performance criteria are:

-- 60 degree rotation angle

-- 20 - 51 degree boom inclination angle

-- 2 tons @ 8 ft/min hoisting rate

-- 47.78 cm/min boom tip positioning rate

-- 4000 lunar lbs. maximum lifting load at 6.26 m from the rear of the platform with the boom at maximum inclination

CONSTRAINTS

Because of the high cost of transportation to the moon -- approximately $15,000 per pound -- weight is the most important constraint. The lifter will also be designed for easy assembly in lunar orbit and will connect to the skitter at only three points.

Other design constraints involve lunar environmental conditions. These include:

-- gravity is 5.4 ft/s^2

-- temperatures range from -250 F to 250 F

-- the atmosphere is a hard vacuum

-- radiation is the primary method of heat transfer

-- large thermal gradients exist between shaded and unshaded surfaces (approx. 400 F)

DESCRIPTION OF DESIGN

PLATFORM

The platform acts as the base of the lifting implement assembly. The boom connects to it at three points via a universal type joint and two actuators mounted on gimballing interfaces.

The platform is an equilateral triangle, with sides of 1.65 meters. It is constructed of a three inch diameter tubular Titanium alloy (Ti-6Al-4V). The platform has an interface on the bottom of each corner to connect it to the SKITTER platform. These interfaces are on 1.60 meter centers. Each interface consists of a two inch diameter steel ball mounted on a one inch diameter, one inch long steel shaft. Each interface is secured to the platform a 1"-8 diameter titanium bolt. The top mounting plate for the power supply rests on the platform, secured by four 1/2"-13 titanium bolts, one at each corner.

The boom attaches to the platform at the rear vertice of the base by means of a universal type joint mounted on a rotating base. This universal joint allows for two degrees of freedom of the boom as well as resisting the torque exerted on the boom by the actuators. It is made of a titanium alloy and will resist 6305.78 Newton-meters of torque. The effective range of motion is 60 degrees in the horizontal plane and 20 to 51 degrees in the vertical plane. The entire interface is protected from lunar dust by a flexible dust boot attached to both the boom truss and platform.

Each actuator attaches to the platform 1.60 meters from the base of the boom at each corner via a gimbal type interface, also constructed of the a titanium alloy. These gimbal interfaces support the bases of the actuators as well as the drive motors. See the actuator drawings in Appendix 1. These interfaces are also protected by a flexible dust boot. The total mass of the platform assembly, excluding the mass of the actuators, gimbals, and fuel cell top plate is 61.85 kg.

BOOM

A triangular frame truss is the basis for the boom design. A triangular truss is 15% lighter than a square frame truss, and this loss in weight is beneficial both from an economic and dynamic standpoint. The boom will be controlled by the actuators that are connected to the underside of the truss.

The sizes of the truss members was determined through the use of GTSTRUDL. Failure for the columns was determined using Euler's Formula for the critical loading on a column. Another consideration in the member design was the slenderness ratio (L/K) which needs to be as small as possible. Actual calculations can be found in Appendix 2. Members will be tubular in shape and the diameters will range from 1.25 to 1.5 I.D. and 1.5 to 1.75 O.D.

Tension members are designed to take a ten kip load in buckling, where, in members of this type, the allowable tensile load is 1000 times that of the allowable compressive load. Compression members are designed with a factor of safety of at least two. 13.6:1 is the final length to width ratio, which was determined iteratively. This gives a final length of 10.2 m and width of .75 m.

Thirty-five titanium joints will hold the boom truss members together. Each joint has a node with tube-shaped connectors protruding from it. Each truss member will be tapered to fit into the connector, then a rapid-action lock assembly consisting of a cylindrical sleeve will slide over the junction between the truss member and connector to lock the two components together. This simple insertion method allows the astronaut to use only one hand for assembly, and this method was tested by Lockheed and found to be adequate from a human factors standpoint.

The boom will be oriented such that the vertices of the triangular frames form the top of the truss while the bases of those triangles form the bottom. (See Boom Truss Assembly drawing in Appendix 1) There are eleven triangular frames spaced .9 m apart down the length of the boom. At each end, three .74 m long truss members attach to the vertices of the triangular frame and are joined together at a point. To provide the needed support for the truss, 1.17 m long cross members are used between each triangular frame; one on each face of a section between frames.

A total of 99 truss members make up the boom: 6 .74 m long end members, 33 .75 m long triangular members, 30 .9 m long section members, and 30 1.17 m long supports. The members are tubular and made out of a graphite-polyimide composite. The overall mass of the boom is 97 kg.

ACTUATORS

The motion of the boom is accomplished through the use of two power screw linear actuators. Each one is attached to the platform and to the boom via gimbal type interfaces. Lubrication of the actuators will be achieved by using dry graphite since regular lubricants cannot withstand the extreme temperatures on the lunar surface.

Each actuator attaches symmetrically at each of the front vertices of the platform. Each also has a collar attachment on the boom. This non-rotating, threaded collar is attached to the gimbal interface on the boom, through which the screw passes. As the screw is rotated, the collar translates linearly along the axis of the screw. This motion repositions the boom. The two boom attachment points are at the second and third triangular frames forward from the base. This offset is necessary to insure clearance of the actuators for all positions of the boom.

The actuators are Duff-Norton model UM-9816, Rotating Machine Screw Actuators, rated for a 15 ton load, with all major components machined from the Ti-6Al-4V alloy. Option #1 from the catalog, with a 32:1 worm gear ratio, is used. With this option, the maximum actuator collar translation is 12.5 cm/minute, which yields a maximum boom tip positioning rate of 47.78 cm/minute. The maximum distance between the actuator base and collar occurs when the boom is at 52 degrees elevation and zero degrees offset. For the actuator attached at Joint #9, this distance is 1.8925 meters, and for the Joint #7 actuator, the distance is 1.1795 meters. The diameter of the screw is 3.81 cm (1.500 in.).

The actuators are driven by a variable speed, reversible electric motor, with a power rating of 3/4 Hp. This motor is mounted on the gimballing interface on the platform, and is coupled to the worm gear drive shaft of the actuator.

Each actuator is protected from lunar dust by two telescoping dust boots, one attached to the platform and the collar, such that the gimbals are protected, with the other attached to the collar and a rotating fitting on the end of the screw shaft.

The mass of the complete actuator system, including boom and platform gimbal assemblies, actuators, motors, and dust boots is 314 kg.

HOIST SYSTEM

The hoist system includes an electric hoist powered by a one horsepower DC motor, 22 meters of Kevlar cable, and a single pulley block and tackle. The hoist is mounted the lifter platform. The Kevlar cable runs from the hoist to the top of the boom, over a 25 inch diameter roller and down into the block and tackle.

The hoist receives a maximum of one horsepower from the DC motor. The use of the DC motor enables the lifting rate to be varied according to the task. This amount of power enables the hoist to lift one ton at a rate of sixteen feet per minute. The hoist can reel in 12 meters of Kevlar cable, which is enough to reach from the lunar surface to the top of the boom at its maximum lifting height.

The Kevlar cable is 1/2 inch in diameter and has a mass of 3.02 kg. The cable is covered with a 1/16 inch thick sheath of aluminum for protection from radiation. This sheath requires a radius of curvature of 25 times the radius of the cable at points where the cable curves. For this reason, the pulley is 12.5 inches in diameter. The block and tackle is made of a titanium with a mass of 6.8 kg. The hoist and motor have a mass of 100 kg, making the total mass for this system 109.82 kg.

POWER SUPPLY

The United Technologies Corporation's Space Shuttle power system provides the power for the lifter. The system consists of the fuel cell, two fuel storage tanks, fuel delivery lines and power transmission lines. The entire system is mounted in the triangular platform of the SKITTER body.

The power plant is 35 cm high, 38 cm wide, and 101 cm long with a mass of 91 kg. The top half of the plant is cylindrical and the bottom half is rectangular. The cell is mounted in the center of the SKITTER body and is flanked by a fuel and an oxidant tank.

Two tanks are mounted below the interface. They contain hydrogen and oxygen as fuel and oxidant, respectfully and are cylindrical with a ten centimeter diameter and a 101 cm height. The tanks are constructed of Ti-6Al-4V and have an empty mass of 10.73kg. Filled, the hydrogen tank has a mass of 15.73 kg and the oxygen tank has a mass of 50.73 kg. The fuel and oxidant travel through 1/4 inch I.D. stainless steel tubing from the tanks to the fuel cell.

The power is transmitted through approximately fourteen meters of fifteen gauge insulated copper wire which runs through Armourflex conduit to the hoist, actuator motors, and lights. The conduit is fastened to the body and boom with titanium clamps and rivets.

The cell and tanks are held firmly between two plates. The top plate is fastened to the lifter interface and the bottom plate is fastened with six 1/2 inch threaded rods to the top plate. The plates are Ti-6Al-4V cast to "cup" the tops and bases of the equipment. The rods pull the plates together, exerting a vice-type effect on the tanks and the fuel cell. The rods are permanently attached to the top plate, and have a "tee-type" nut handle which raises and lowers the lower plate and therefore the poser system. The six "tee-type" nut handles are made of stainless steel and are the lowest point in the entire lifting implement, extending approximately 110 cm below the platform and into the SKITTER base.

A 61 liter poly tank surrounds the bottom portion of the fuel cell. The tank has a sill cock to drain the water that the fuel cell has generated. The total mass of the power supply is 162.5 kg.

CONTROLS AND OPERATION

The lifter is operated remotely by using two manually controlled input devices: a joystick for the boom control and a lever for the hoist control. The signal travels from the operator controls to a microprocessor which converts it to a set of instructions for the actuator and hoist motors.

To insure proper functioning of the lifter, several parameters have been chosen as feedback to both the microprocessor and the operator. These include stress in certain members of the boom, torque needed to turn the actuator motors, force needed to lift a load, and boom position. These parameters are measured by transducers, sent to the microprocessor, and then displayed for the operator.

For versatility of operation, the lifter has two video cameras and four floodlights mounted on it. These will enable the lifter to be remotely operated during the day or night. One camera is mounted on the boom at the tenth triangular frame from the base and the other is mounted at the base of the boom. The operator has controls for the focus, direction, and zoom for these cameras. Two of the lights are mounted on the platform and the other two are mounted on the boom. The total mass of the cameras and lights is 5 kg.

ANALYSIS OF DESIGN

STRUCTURAL FORCES AND LOADS

Through the use of GTSTRUDL, the boom was placed in several positions by varying the boom angle and the offset angle program inputs. (The offset angle is the horizontal angle the boom centerline is offset from the platform centerline.) The forces in each actuator was calculated for a given load of 50 kilograms. The results can be found in Appendix 1.

The boom length was calculated by placing the maximum load (lunar life support module) at the "tip line", and calculating the required length to lift this load to the level of the platform. See Lifting Capability drawing in Appendix 1. A load vs. radius curve which assesses the lifting capability of the lifter is also included in Appendix 1.

BOOM FORCES

The boom design calls for an elaborate truss which must be analyzed by a computer program. The computer software chosen is marketed by Georgia Tech and is called GTSTRUDL. GTSTRUDL is a program designed by the Civil Engineering department of Georgia Tech and provides the user with many bits of information that would have taken much too long to compute by hand. A short description of GTSTRUDL is therefore appropriate to explain some of the design decisions.

The input of the truss into GTSTRUDL is a matter of describing the truss as a system of joints and member incidences. Units were designated to be meters and degrees therefore all values following will also be in these units. The next step is to generate values for all of the joints throughout the truss.

This can be done in two ways: 1.) specify exactly what the x, y, and z coordinates of the joints are and 2.) generate a complete line of joints by using the "generate" command. Now the member incidences must be specified. Material properties such as density, modulus of elasticity and cross sectional area are also entered. The final piece of input is the initial load at the end joint.

The output received from GTSTRUDL is done so by routing the input file through a stiffness matrix. The "stiffness analysis" command is used to call the stiffness analysis subroutine. The stiffness analysis procedure is a linearly elastic, small displacement, static analysis of structures. These structures are composed of a finite number of joints and nodes. A matrix formulation is used and the equations to be solved are the stifness equations expressed in terms of the unknown joint displacement components.

One final word should be mentioned concerning the use of GTSTRUDL. This computer software system is by no means a computer design system. It is a structure analyzing system that treats any design and computes any number of several parameters. GTSTRUDL has been created with the engineer in mind. The engineer must make all design decisions and control the system to help in the laborious methodology. Likewise, all design considerations were made by this design group.

Runs for several configurations, as well as the critical configuration (20 degree boom angle), can be found in Appendix 2. Some of this output was used to design the tubular truss members, and other output included the weight of the boom and length of the actuators.

The boom was modeled as a space truss, meaning that the members are only joined by perfect pin joints. No moments can be carried by any of the joints. The exception to this generality is the actuators. The joint between the actuator and the boom was modeled as a frame joint, able to carry moments in all directions. Since the actual joint has to move on two axes to allow boom motion, the moment holding ability along these axes was disabled by a moment release command.

MATERIALS

Several types of materials are used in the construction of the lifter. Because weight is the most crucial factor in this design, an emphasis was made to consider composite materials since composites are several times lighter than metals.

Since vendor supplied bolts, actuators, joints, hoists, and motors are used, they are made of various types of steel. The platform, which consists of several tubes welded into triangular shapes, is constructed from a titanium alloy (Ti-6Al-4V). This alloy has a density of 4438 kg/m^3, a melting temperature of 3000 F, and a tensile modulus of 16.5 x 10^6 psi.

A graphite-polyimide composite material is used for the tubular truss members in the boom structure. Polyimides have been studied for aerospace applications because they can be used with glass and carbon fibers to produce composite laminates that are relatively void-free. These polyimide laminates are mechanically strong up to temperatures around 600 F. For example, the polyimide PMR-15 developed by NASA Lewis has a flextural modulus at 600 F of 14.6×10^6 psi. Because they are stable against radiation fluxes and still retain their performance characteristics in a hard-vacuum or other moisture-free environments, polyimides are adaptable for use on the lunar surface.

Some research was done by McDonnell Douglas on pultruded graphite-polyimide rods made from a DuPont NR150 resin for space structure applications, and this is the material which will be used to form the boom truss. This material was made to encounter a service temperature up to 260 C and was coated with a protective polymeric coating. The rods had a density of 1450 kg/m^3, and average tensile modulus of 26.1×10^6 psi, and a flextural modulus of 20.4×10^6 psi.

HOIST SYSTEM

The lifter uses an electric hoist built by Lift-Tech International, Inc. The Shaw-Box Series 800 hoist is modified to accomidate a DC motor, Kevlar cable, larger drum radius, and components manufactured from titanium and aluminum where practical. The drum is large enough to accommodate all of the cable without over-wrapping. The motor brake is operated by the magnetic field produced by the motor and is held in the set position by a compression spring and is released when current is flowing to the motor. An upper limit switch cuts power to the motor when the hoist cable reaches its maximum height. The mass of the electric hoist is 220 pounds.

The hoisting cable is an aramid fibre rope made by Greening Donald Co.,Ltd. The diameter of the cable is 12.7 mm and has a mass of 0.1268 kilograms per meter. The total mass of the cable is 2.79 kg. Using the industry standard factor of safety of 5 for hoisting cables, this size cable is safe for loads up to 10,546 kg. The aluminum sheathing that is required to protect the kevlar from the effects of radiation has a mass of 0.010 kg per meter for a total mass of 0.23 kg. The combined mass of the cable and the sheathing is 3.02 kg. This cable has a mass one-fifth that of steel rated for the same load.

The roller and pulley must be of sufficient diameter to accommodate the aluminum sheathing, which needs a 25 to 1 ratio between any radius of curvature and the cable radius. Therefore, the diameter of the pulley is 31.75 cm. The roller has a diameter of 63.50 cm to allow the cable to be supported at the center of the roller and thereby minimize twisting in the cable.

POWER SUPPLY

Fuel cells show their usefulness in numerous space missions. Increased power capacity, longer operation time, modular design and light weight make fuel cells an attractive power source for space applications. The lifter uses the space shuttle fuel cell designed by United Technologies Corporation. This newly designed cell is 20 kg lighter than the Apollo system cell and delivers six to eight times more power. Pressurized hydrogen and oxygen are delivered to the cell to produce .746 KW for the hoist, 1.12 KW for two linear actuators, and 2 KW for lights and video cameras.

The system produces an average output of 3.86 KW, but can deliver 436 amps at 27.5 volts for a peak power of 12 KW. The cell can produce the average 3.86 KW for 10 hours of continous operation without replacing fuel and oxidant tanks.

The tanks have an internal volume of 793 cc. The hydrogen tank contains 5 kg of fuel at 1180 psi and delivers it at an average rate of .14 grams/sec. The oxygen tank contains 40 kg of fuel at 594 psi and delivers it at an average rate of 1.11 grams/sec. Approximately 60 liters of water are produced per each load of fuel. A 61 liter tank collects this product and then be drained with each refueling.

The empty tanks are replaced by loosening the "tee-type" nuts and lowering the entire system (See Power Supply drawing in Appendix 1). The tanks are then disconnected from the cell and lifted from their cups. Fresh tanks are then inserted into the cups and connected to the cell. Retightening the "tee-type" nuts raises and then secures the entire system. The nuts should be tightened uniformly till snug to ensure proper mounting. The tank is drained through the sill cock into a transport tank for use in the space station.

The power is delivered with 14 gage wire to a bus located at the base of the boom. Separate leads connect the equipment. The wiring is protected with Armorflex conduit. The tanks and mounting apparatus are made from a titanium alloy, T1-6A1-4V.

DEPLOYMENT AND STORAGE

It is assumed that the lifter will be one of the first, if not the first, piece of lunar equipment to be deployed to the moon. This is almost a necessity, since part of the lifter's performance objectives is to load and unload all of the other equipment that will be needed to construct the lunar base. A novel deployment idea would be to somehow "land" the SKITTER and lifting implement on the lunar surface as one unit. This could be accomplished by attaching rockets to the SKITTER, which the lifter could then remove from the SKITTER after the landing. Then, the lifter would be at the lunar surface, in place on the SKITTER, and ready to unload the first LTV.

Since the lifting implement will not be the only implement that the SKITTER will use, it will need to be removed from the SKITTER during the times it is not needed. A simple A-frame stand is an adequate storage device. This stand will need to be eight meters tall with a four meter long cross member that has a ring located at its center. This size will allow the SKITTER to squat and crawl under the A-frame, stand up and hook the lifter to it, and then squat back down and crawl out from under it. The hook which will attach to the A-frame will be mounted onto the boom at the lifter's center of gravity.

OVERALL MASS

The overall mass of the lunar lifting implement is:

Platform	61.85
Boom	97.00
Actuators	314.00
Hoist	109.82
Cameras, Lights	5.00
Power System	162.50
	======
	750.17 kg = ~~2100.5~~ 1650.4 pounds

CONCLUSIONS AND RECOMMENDATIONS

This design approach chosen for a lunar lifting implement for the SKITTER may not be the only solution to the problem of lifting cargo on the lunar surface, but it is the most efficient of the possibilities considered. It is a lightweight, easily transported implement which meets the design criteria for load size and weight. The lifter is completely remote controlled and capable of operation at all times, day or night, while the fuel cell power supply provides power at all times and under all conditions. The implement can be removed and stored to allow SKITTER to perform other tasks.

However, some disadvantages exist in the design. The range of motion is somewhat limited because of its 60 degree swing angle and 20 to 51 degree radial positioning angle range. These constraints are caused by the use of the actuators. The power supply is limited by the ten hour life of fuel cells. These limitations are justified by the stability added to the design by the actuators and by the efficiency and safety inherent in the fuel cells.

Any payload that will be delivered to the moon can be handled by the lifter. If the load cannot be "dead-lifted", techniques exist in the construction industry for lifting loads greater than the capacity of the lifter. The modules can be lifted, one end at a time, onto a transportation device. All loads transported to the moon during the building phase of the base can be handled by the lifter.

In conclusion, this design group feels that the lifter presented above represents the most stable and efficient solution to the design problem.

ACKNOWLEDGEMENTS

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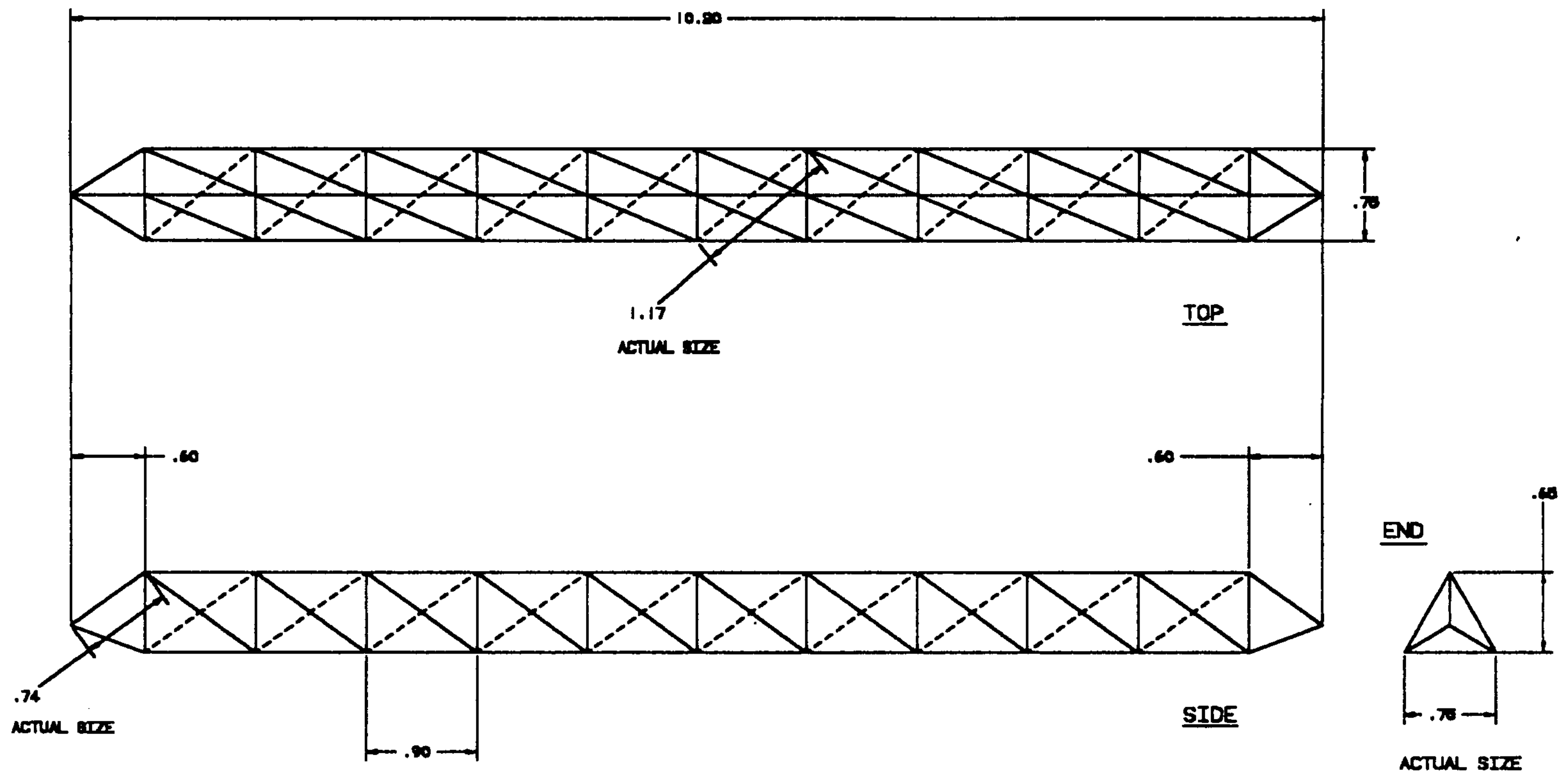
APPENDIX 1



NOTE: DASHED TRUSS MEMBERS APPEAR BEHIND OR BELOW SOLID MEMBERS

*NOTE: ALL DIMENSIONS ARE IN METERS

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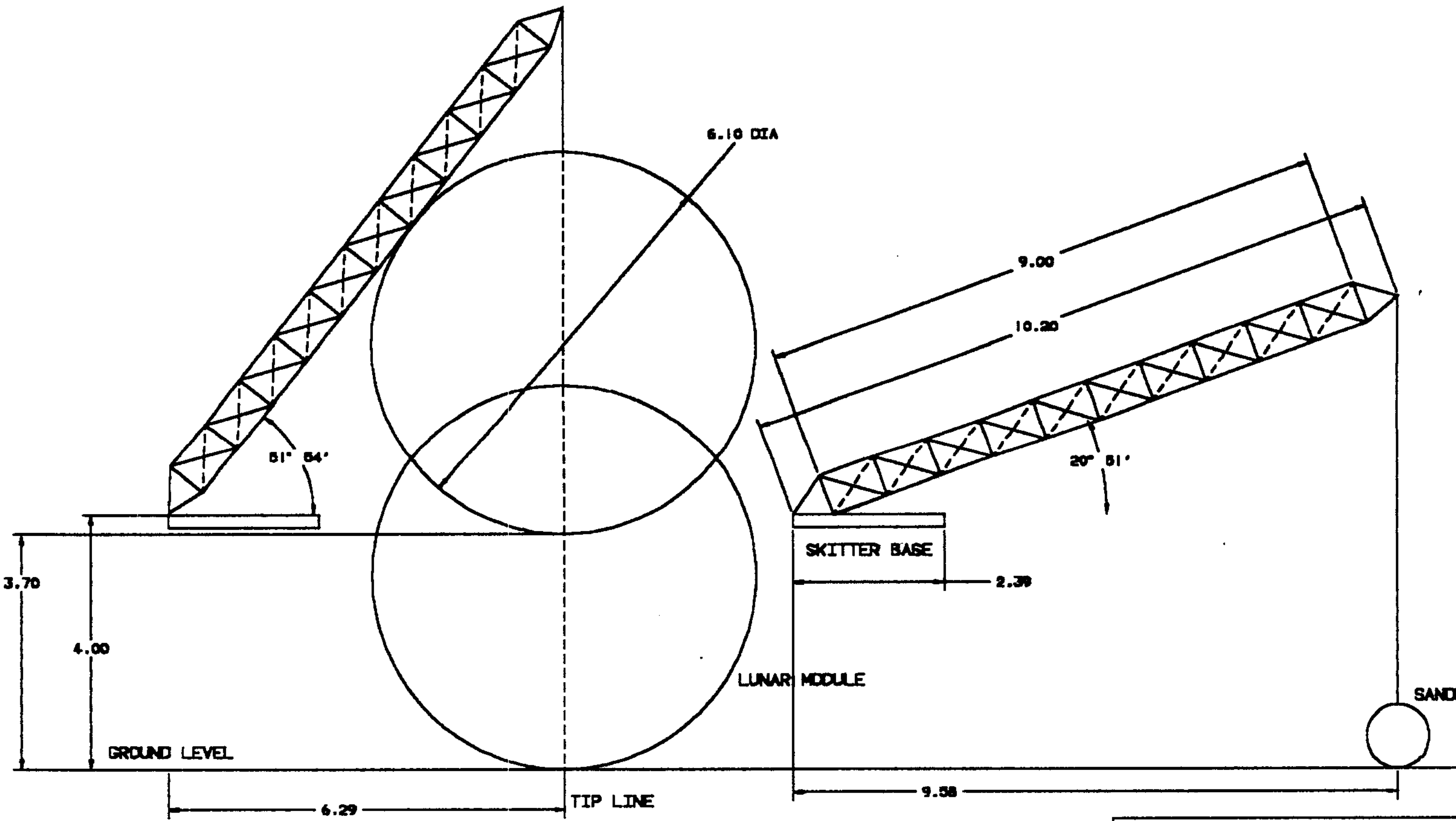
LUNAR LIFTING IMPLEMENT
DRAWING: BOOM TRUSS ASSEMBLY



NOTE: DASHED TRUSS MEMBERS APPEAR BEHIND OR BELOW SOLID MEMBERS

*NOTE: ALL DIMENSIONS ARE IN METERS

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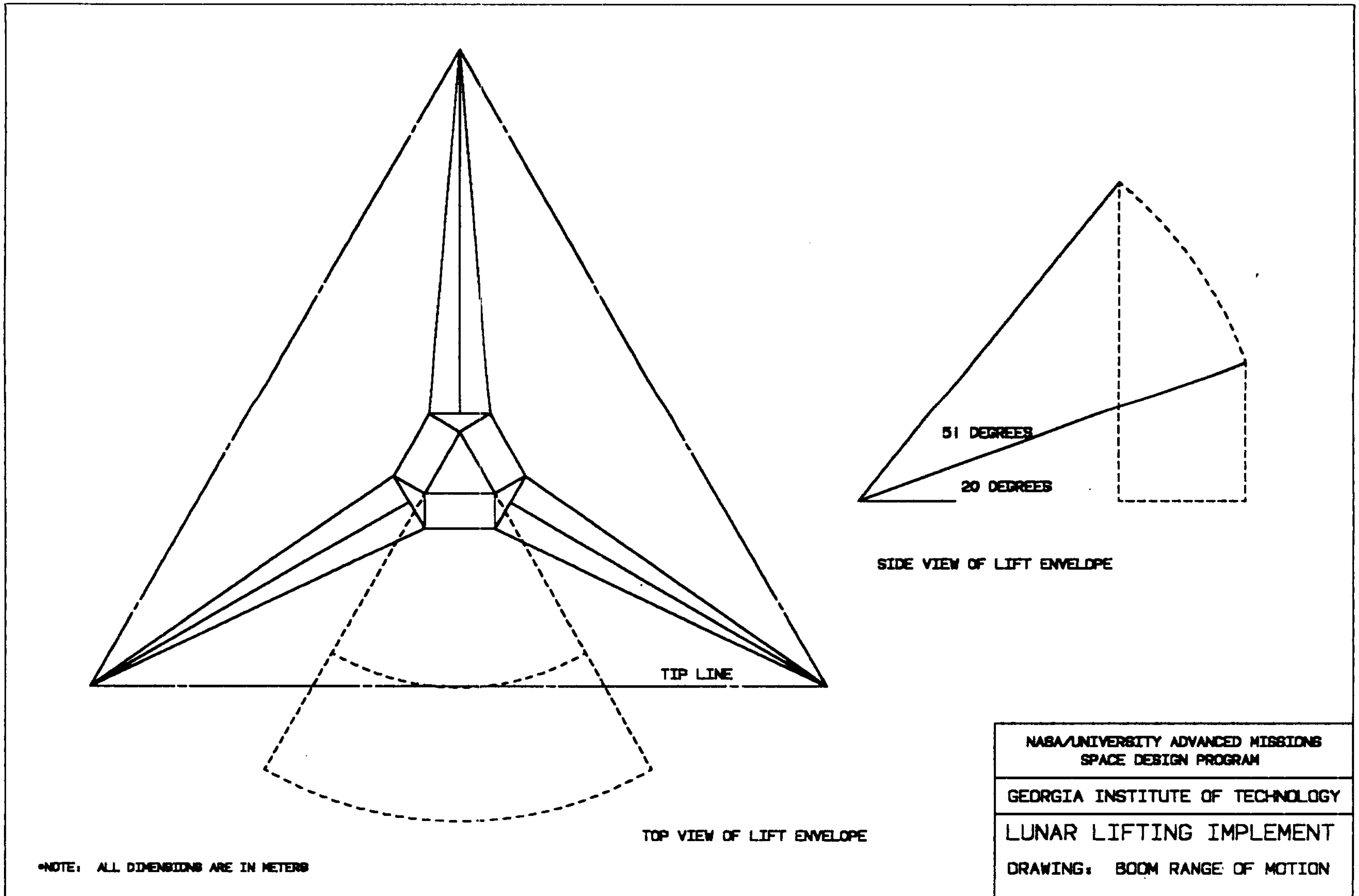
LUNAR LIFTING IMPLEMENT
DRAWING: LIFTING CAPABILITY



51 DEGREES
20 DEGREES
SIDE VIEW OF LIFT ENVELOPE
TIP LINE
TOP VIEW OF LIFT ENVELOPE
*NOTE: ALL DIMENSIONS ARE IN METERS
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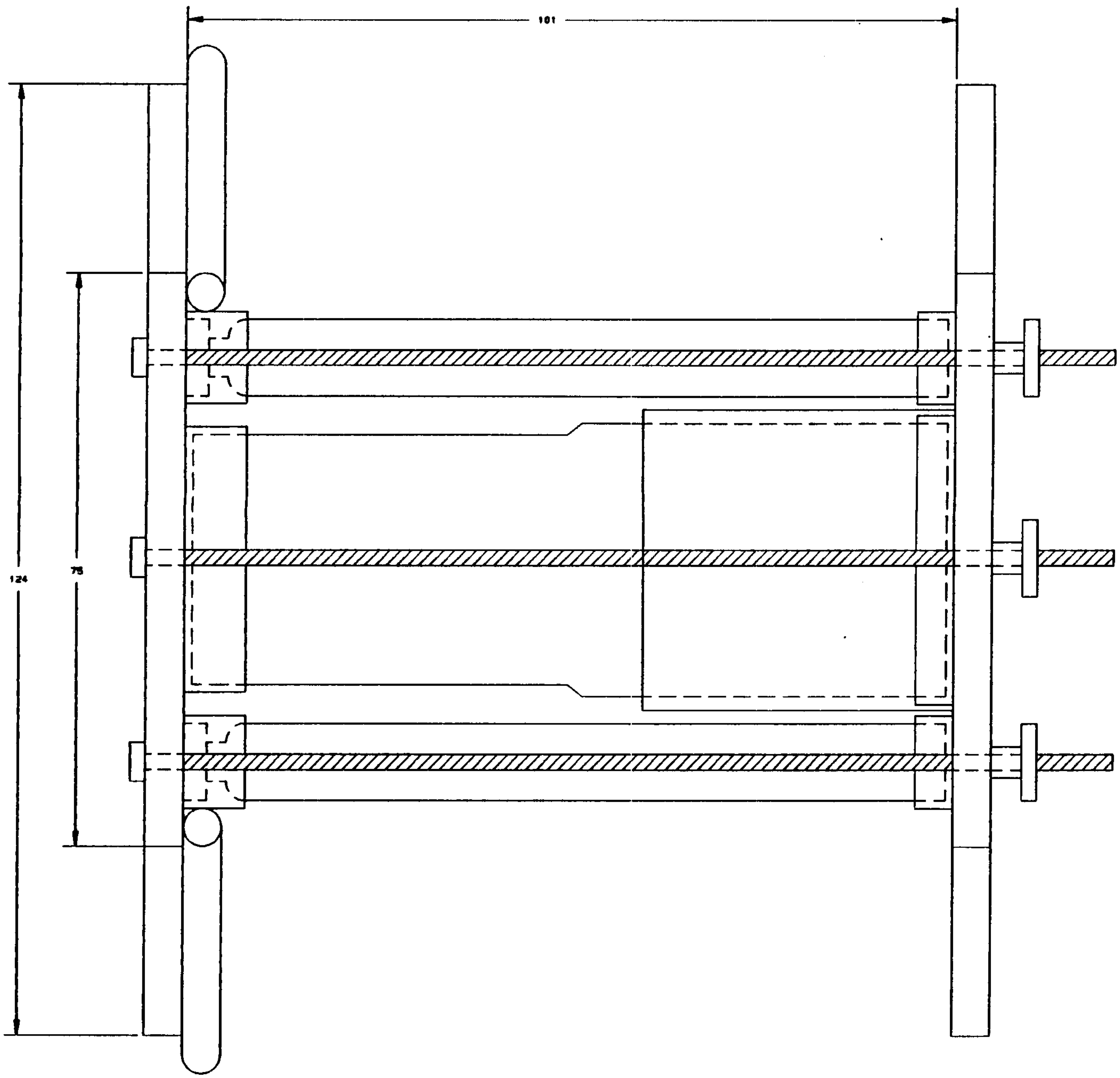
GEORGIA INSTITUTE OF TECHNOLOGY
LUNAR LIFTING IMPLEMENT
DRAWING: BOOM RANGE OF MOTION

POWER SUPPLY



FRONT VIEW

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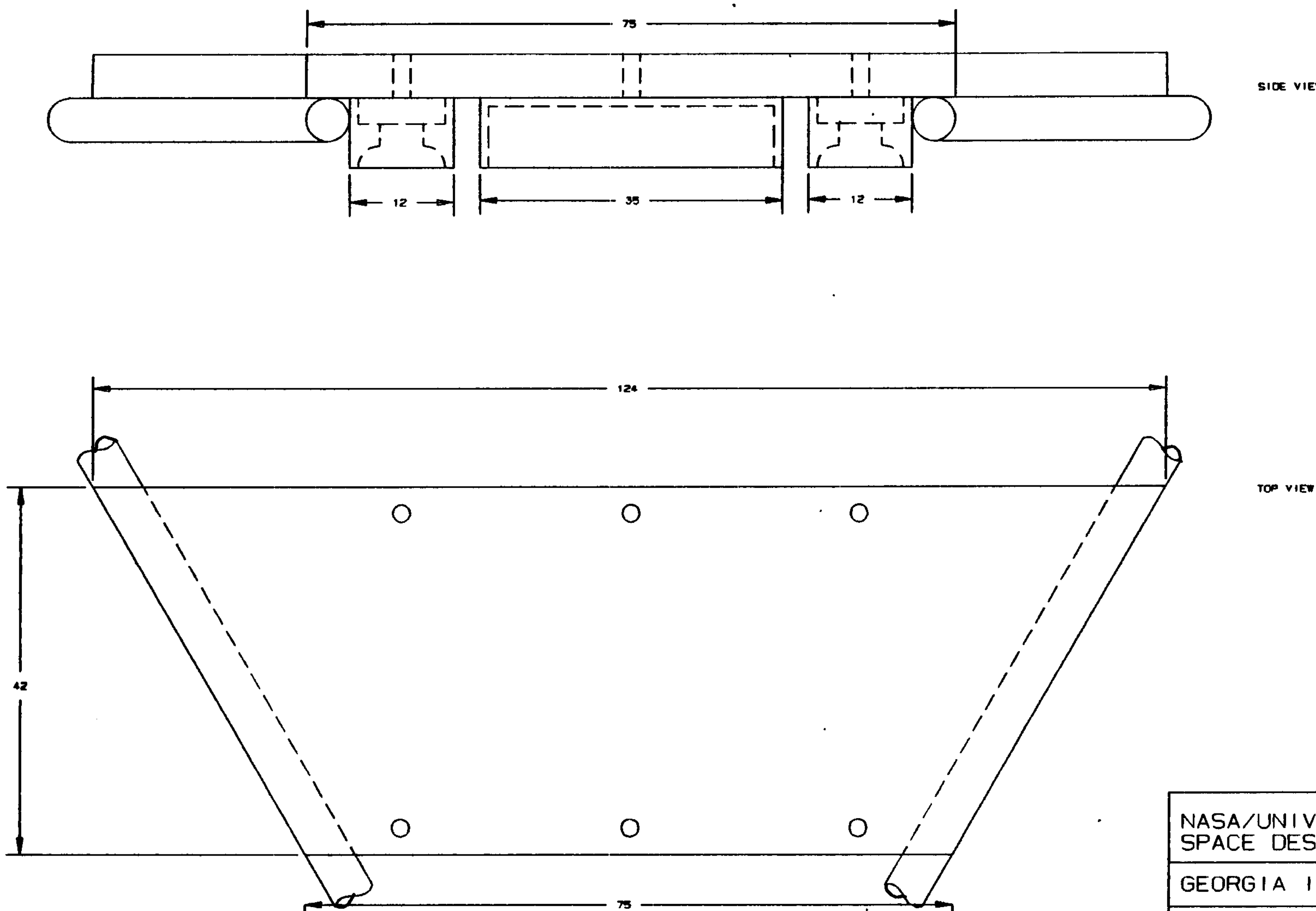
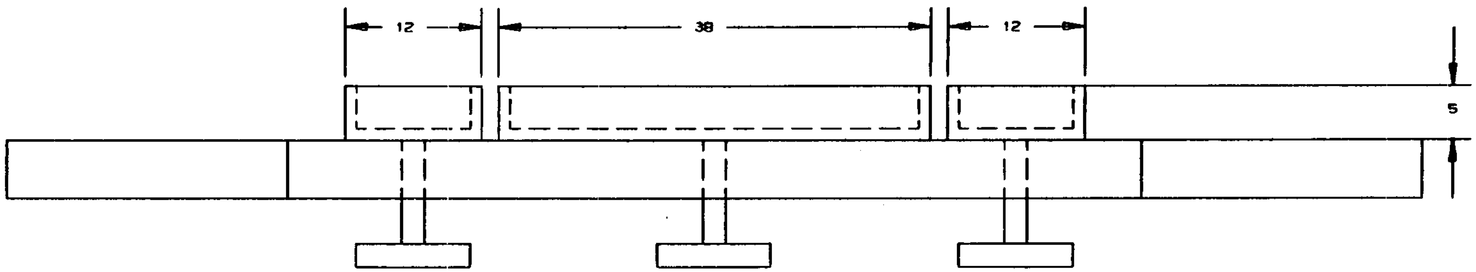
LUNAR LIFTING IMPLEMENT DRAWING: POWER SUPPLY
NOTE: ALL DIMENSIONS IN cm

TOP PLATE



NASA/UNIVERSITY ADVANCED MISSION SPACE DESIGN PROGRAM
GEORGIA INSTITUTE OF TECHNOLOGY
LUNAR LIFTING IMPLEMENT
DRAWING: TOP PLATE
NOTE: ALL DIMENSIONS IN cm

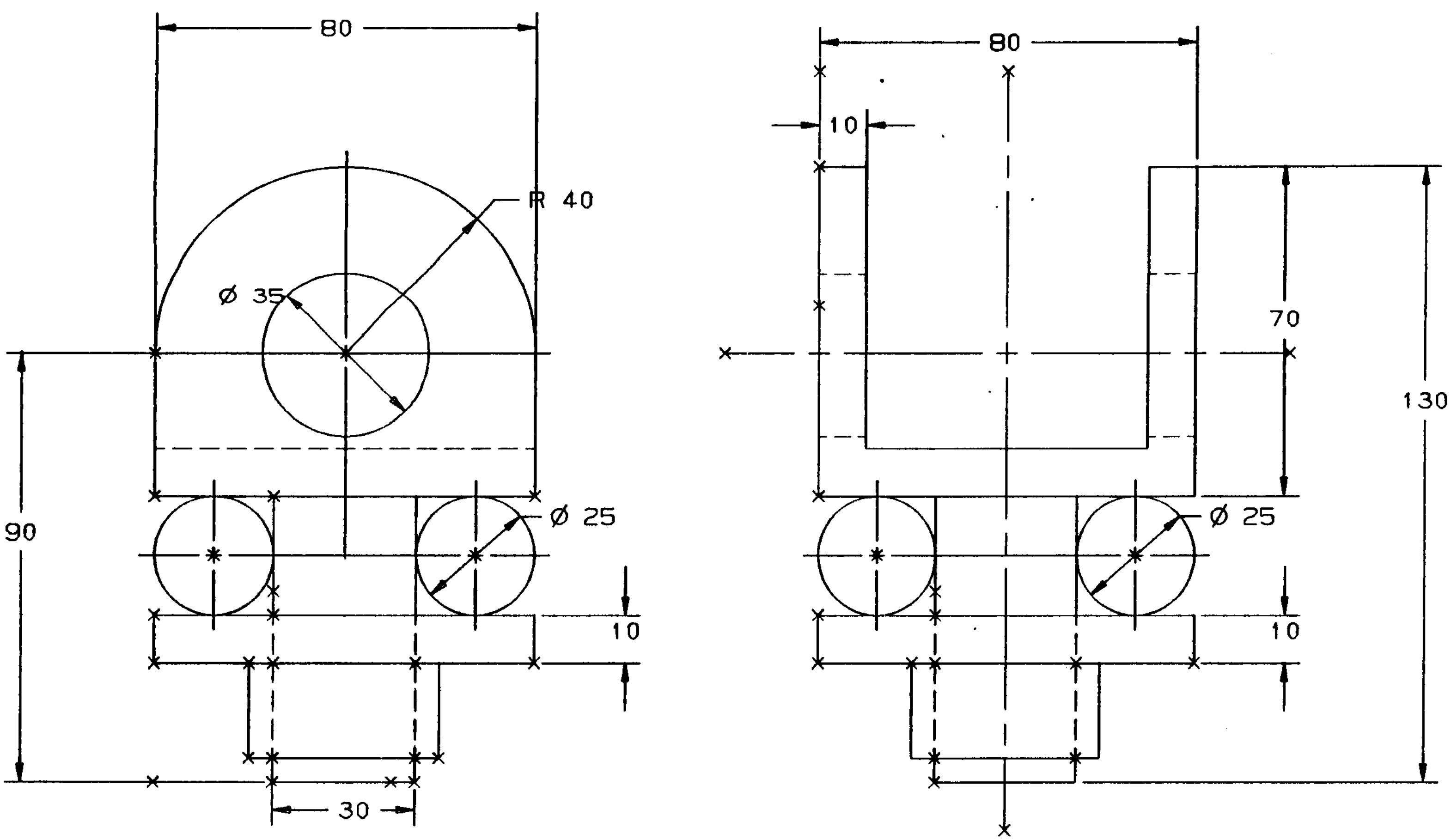
BOTTOM PLATE



SIDE VIEW

NASA/UNIVERSITY ADVANCED MISSION SPACE DESIGN PROGRAM
GEORGIA INSTITUTE OF TECHNOLOGY
LUNAR LIFTING IMPLEMENT DRAWING: BOTTOM PLATE
NOTE: ALL DIMENSIONS IN cm

NOTE: ALL DIMENSIONS IN MM

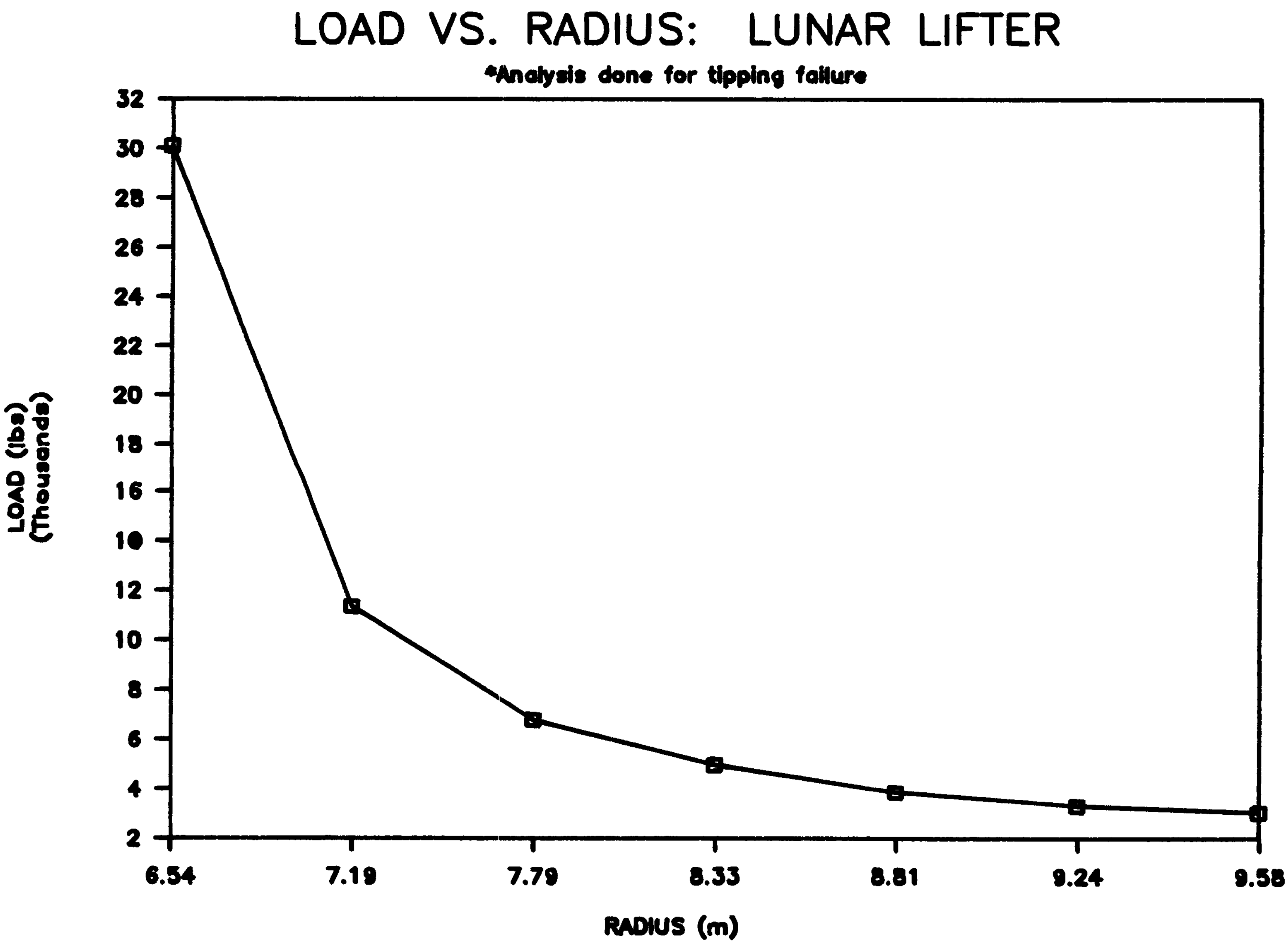


NOTE: BEARING PACKINGS NOT SHOWN

NASA/UNIVERSITY ADVANCED MISSIONS SPACE PROGRAM

GEORGIA INSTITUTE OF TECHNOLOGY

UNIVERSAL JOINT


LOAD VS. RADIUS: LUNAR LIFTER
*Analysis done for tipping failure
LOAD (lbs)
(Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
6.54
7.19
7.79
8.33
8.81
9.24
9.58
RADIUS (m)

NASA/UNIVERSITY ADVANCED MISSIONS SPACE DESIGN PROGRAM
LUNAR LIFTING IMPLEMENT

Table of Actuator Forces and Lengths
with Respect to Boom Elevation Angle and Offset Angle
from GTSTRUDL

Actuator #1 is joined at the second boom joint, right platform corner
Actuator #2 is joined at the third boom joint, left platform corner

For Boom Angle = 20 degrees Load = 50 kilograms

Offset Angle (in degrees)	Actuator #1 Length (mtrs)	Actuator #1 Force (lbs)	Actuator #2 Length (mtrs)	Actuator #2 Force (lbs)
30 to left	0.965	236.96	0.551	342.71
15 to left	0.812	267.89	0.631	314.59
Centered	0.643	298.65	0.724	277.43
15 to right	0.589	335.31	0.873	234.98
30 to left	0.506	369.43	0.994	208.42

For Boom Angle = 35 degrees Load = 50 kilograms

Offset Angle in degrees	Actuator #1 Length (mtrs)	Actuator #1 Force (lbs)	Actuator #2 Length (mtrs)	Actuator #2 Force (lbs)
15 to left	0.894	243.79	0.719	292.43
Centered	0.736	273.88	0.822	251.89
15 to right	0.681	312.76	0.913	229.88

For Boom Angle = 51 degrees Load = 1800 kilograms

Offset Angle in degrees	Actuator #1 Length (mtrs)	Actuator #1 Force (lbs)	Actuator #2 Length (mtrs)	Actuator #2 Force (lbs)
Centered	1.179	10715.71	1.892	9668.64

APPENDIX 2

Sample calculations for boom members:

Size D members-

Outside diameter = 1"
Inside diameter = .75"
Area = (Pi/4) x (OD - ID) = .344 in.^{2} or 221.6 mm^2
K = .3125
P_{cr} = 7737.2 lbs.
Allowable tension load = E/A = 62.7 x 10^3 kips

Size C members-

OD = 1.5"
ID = 1.25"
K = .488
A = .540 in.^{2} or 348 mm^2
P_{cr} = 29,651.6 lbs.

Size B members-

OD = 1.75"
ID = 1.5"
K = .576
A = .638 in^2 or 411.2 mm^2
P_{cr} = 48,806.8 lbs.

MASS OF PLATFORM

ATTACHMENTS:

$$3\left(\frac{4}{3}\pi r^3\right)+3(\pi r^2 h) \simeq 4\left(\pi \tfrac{4}{3}(2.54cm)^3\right)+3\left(\pi(1.29cm)^2 2.54cm\right) = 245.76cm^3$$

$$205.02 + 39.33$$

$$(245.76\ cm^3)\left(\frac{1\ m}{100\ cm}\right)^3\left(4438\ kg/m^3\right) = 1.0907\ kg$$

1.65 3" TUBULAR RODS AT 2" ID

$$3\left((1.65m)\pi\left(\left(\frac{3(2.54)}{2}\right)^2-\left(\frac{2(2.54)}{2}\right)^2\right)\right)\left(4438\ kg/m^3\right) = \boxed{55.657\ kg}$$

U-JOINT

$$\pi(1.5cm)^2(6.0cm)+(1cm)(6cm)(8cm)+2(3cm)(1cm)(8cm)+\pi(4cm)^2(1cm)-2(\pi(2cm)^2(1cm))$$

$$8\left((1.25)^3\tfrac{4}{3}\pi\right)+(1cm)\pi\left((4cm)^2-(1.5cm)^2\right) = \boxed{272.19\ cm^3}$$

$$4438\ kg/m^3 \cdot 272.19\ cm^3 = 1.208\ kg$$

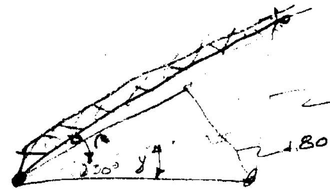
3 TRIANGULAR PLATES 3cm thick, 15 cm/SIDE

$$= .0009\ m^3 \rightarrow \boxed{3.8915\ kg}$$

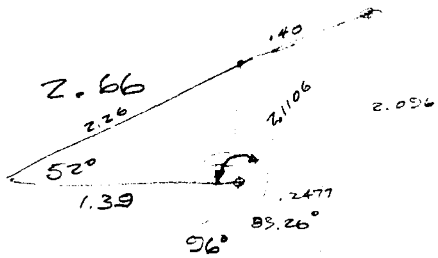
TOTAL → $\boxed{61.8535}$

ACTUATOR ANALYSIS FOR COLUMNAR FAILURE AT MAX LOAD ≈ 4000 ~~8000~~ lbs

W/ $\gamma = 0°$, $\beta = 52°$



2.257 METERS AT FULL LOAD



$\boxed{\approx 88.86'' = \ell}$

$K = \frac{d}{4}$ ∴ slenderness ratio $\frac{\ell}{k} = \frac{88.86}{2.5/4} = 142.18$

$d = 2.500''$ FOR MODEL 9025 DUFF NORTON

ALLOY → Ti-6AL-4V

$S_y = 155{,}000$ psi

$E = 16.5 \times 10^6$ psi

$\left(\frac{\ell}{k}\right)_1 = \sqrt{\frac{2\pi^2 CE}{S_y}} = \sqrt{\frac{2\pi^2 (1)(16.5\times10^6 \text{ psi})}{(155\times10^3 \text{ psi})}} \Rightarrow \left(\frac{\ell}{k}\right)_1 = 45.84$

$\left(\frac{\ell}{k}\right) > \left(\frac{\ell}{k}\right)_1$ ∴ EULER COLUMN

$P_{CR} = \frac{\pi^2 EI}{\ell^2} = \frac{\pi^2 (16.5\times10^6 \text{ psi})\left(\frac{\pi (2.5 \text{ in})^4}{64}\right)}{(88.86 \text{ in})^2} = 39{,}545.8$ lbs ← P_{CR}

FOR MODEL DUFF NORTON # 9036 TITANIUM SCREW

$\rho = .160$ lb/in³ FOR TITANIUM

$P_{CR} = \frac{\pi^2 (16.5\times10^6 \text{ psi})\left(\frac{\pi (3.00 \text{ in})^4}{64}\right)}{(88.86'')^2} = \boxed{82{,}000 \text{ lbs}}$

∴ OK!

540# WHEN MADE OF STEEL AT

$\rho = .282$ lb/in³ ∴ VOLUME = 1,914.8936 in³

FOR Ti $\rho V = (.160 \text{ lb/in}^3)(1{,}914.8936 \text{ in}^3) = \boxed{306.38 \text{ lbs}}$

$\boxed{= 139.26 \text{ kilo}}$

ACTUATOR FOR COLUMN FAILURE — 30 MAY '87

AT MAX LENGTH OF 74.51 INCHES AND MAX LOAD (FROM GT STRUDL) OF 5365.36 lb_f

ASSUME EULER COLUMN

FOR Ti-6AL-4V

$$P_{CR} = \frac{\pi^2 E I}{l^2} \quad \therefore \quad I = \frac{\pi d^4}{64} = \frac{P_{CR}\, l^2}{\pi^2 E}$$

$$\text{So} \quad d^4 = \frac{P_{CR}\, l^2 (64)}{\pi^3 E} = \frac{(5365.36\,lb)(74.5\,in)^2(64)}{\pi^3 (16.5 \times 10^6\,psi)}$$

$$\boxed{\therefore\ d_{MIN} = 1.389''}$$

SPEED DETERMINATION FOR ACTUATORS

MODEL # 9036 AT $\frac{1}{8}$ CAPACITY (8750 lbs.)

TORQUE FOR OPTION #1 (32:1 RATIO) = 300 in lbs

STD. OPTION ($10\frac{2}{3}$:1) = 500 IN lbs.

$$hp = \frac{\text{lift torque} \times \text{RPM of Worm}}{63{,}000}$$

TURNS OF WORM FOR 1" RAISE OPT #1 — 48

STD. OPT — 16

GO W/ OPT #1 (32:1 WORM GEAR RATIO) CAUSE LESS TORQUE ∴ SMALLER MOTOR

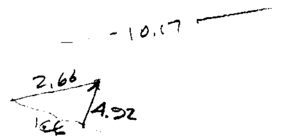
FROM FUEL CELL SUPPLY 3/4 horsepower MOTORS (.559 kW)

∴ MAX RPM OF WORM AT 300 IN lb = 157.5 $\frac{\text{rev}}{\text{min}}$

THUS AT 157.5 RPM FOR WORM ACTUATOR REV WILL BE:

$$(157.5 \text{ RPM FOR WORM}) \frac{1 \text{ ACT TURN}}{32 \text{ WORM TURN}} = 4.92 \frac{\text{IN}}{\text{MINUTE}}$$

THIS TRANSLATES TO A BOOM TIP SPEED



$$\frac{2.66}{10.17} = \frac{4.92}{x} = \boxed{18.81 \text{ IN/MINUTE}}$$

POWER REQUIREMENTS:

1. HOIST → 1 HORSE → .746 KW
2. ACTUATORS → 3/4 HORSE PER → 1.119 KW
3. LIGHTS → 2 KW → 2 KW

$\boxed{3.86 \text{ KW}}$

450 Kg PRODUCES 600 L & 7 KW FOR 36 HOURS ∴

$$\frac{3.86 \text{ KW}}{7 \text{ KW}} = \frac{36}{t}$$

$$t = 65.3 \text{ hrs}$$

FOR 10 hrs OF OPERATION → 45 kg of fuel & OXIDANT

$\boxed{t_{OPERATION} = 10 \text{ hrs}}$

45 Kg OF FUEL & OXIDANT

∴ : 5 kg of H (11 lb)

40 kg O_2 (88 lb)

POWER CALC.

TANK SPECIFICATIONS

$L = 101$ cm

$t = .75$ cm

I.D. $= 10$ cm

$V = \pi(75)^2(101)$

$= 178 \text{ cm}^3$

Ti 6Al 4V: $\rho = \left(.16\ \cancel{\text{lb}}/\cancel{\text{in}^3}\right) \frac{(\text{in})^3}{(2.54\text{ cm})^3} \left(\frac{1\text{ Kg}}{2.2\ \cancel{\text{lb}}}\right)$

$\rho = .0044 \text{ Kg}/\text{cm}^3$

wt/tank : $(.0044)\left[\text{volume}\right]$

$V_{ti} = \left[L(\pi D) + \frac{\pi D^2}{4}\right] t$

$V_{ti} = \pi D\left[L + \frac{D}{4}\right]$

$V_{ti} = \pi\, 10\left[101 + \frac{10}{4}\right] .75$

$V_{ti} = 2439 \text{ cm}^3$

TANK WT $= 10.73$ Kg/tank $=$ (23.6 lb)

INSIDE VOLUME: $\left(\frac{(\pi)(10)}{4}\right)(101)$

$= 793 \text{ cm}^3 = .793 \text{ m}^3$

POWER CALC.

FUEL SPECS:

HYDROGEN:

$PV = mRT$ $\qquad$ $T \approx 40°F$ in ~~SHADE~~

$T = 313°K$

$$P = \frac{(\cancel{5 kg})(.08314\ bar\ \cancel{m^3}/(\cancel{kg\ mol})\ \cancel{°K}\ 313\ \cancel{°K}}{2.016\ \frac{\cancel{kg}}{\cancel{kg\ mol}}\ (.793\ m^3)}$$

$P = 81.4$ bars $= 1180$ psi

OXYGEN:

$PV = mRT$

$$P = \frac{(40 kg)\ .08314\ bar\ m^3/((kg\ mol)\ °K)\ (313\ °K)}{\left(\frac{32\ kg}{kg\ mol}\right)(.793\ m^3)}$$

$P = 41.0$ bars $= 594$ psi

MASS FLOWRATE ($\mathring{m}$)

$\mathring{m}\big|_{P=3.86 kW}$ $\qquad$ $H = 5 kg/10\ hr \cdot \frac{1 hr}{3600} = 1.4 \cdot 10^{-4}\ kg/s$

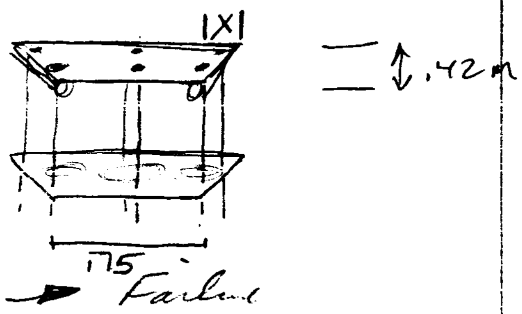
$\boxed{.14\ g/s}$

$O = 40 kg/10 h = 1.11 \cdot 10^{-3}\ kg/s$

$\boxed{= 1.11\ g/s}$

POWER CALC.

MOUNTING APP



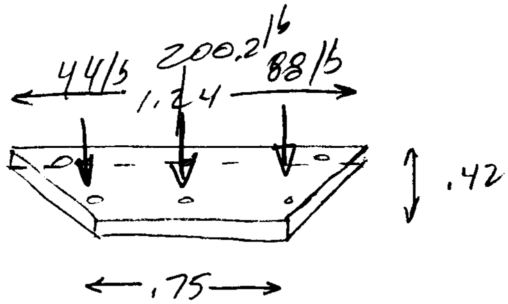
Ti 6Al 4V

σ yield = 128,000 Psi
= 58,180 kg/in²

yield → Failure

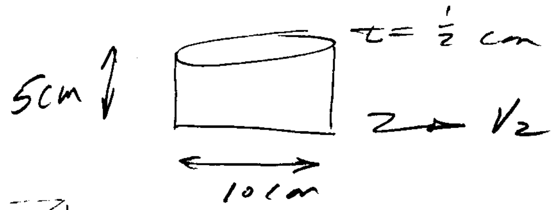
$\tan 30° = \frac{X}{.42\ m}$ X = .243 M

PLATE DIMENSIONS

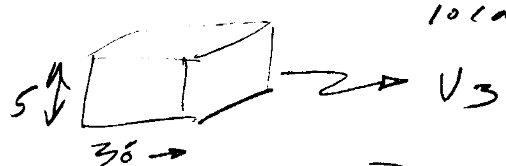


$I = bh^3/12$

$I = (.42) h^3/12 = .035 h^3$



$\sigma = My/I$



$V = (1cm)[(.75)(42) + (243)(42)] = 4170.6\ cm^3$

$V_2 = (10)(\pi)(5)\ 1/2 = 76\ cm^3$

$V_3 = (5)(38)(1/2) = 95\ cm^3$

TOP PLATE 4170 + 2 (76) + 87.5 = 4410 cm³

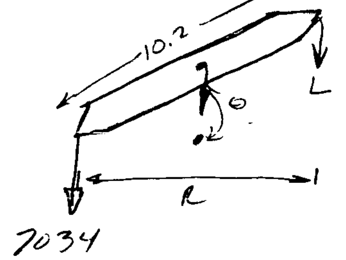
M = .0044 kg/cm³ 4410 cm³ $\boxed{= 19.4\ kg}$

Bottom PLATE = 4170 + 2(76) + 95 $\boxed{= 19.43\ kg}$

FUEL SYSTEM SPECIFICATIONS

H TANK wt	→	1.73 Kg
O TANK wt	→	10.73 kg
TANK Vol	→	.793 m^3
TANK DIM	→	101 x 10 x .75 cm
TOP PLATE wt	→	19.4 kg
Bottom PLATE wt	→	19.43 kg
PLATE DIM	→	
t operation	→	10 hrs
$\dot{m}$ H	→	.14 g/s
$\dot{m}$ O	→	1.11 g/s
1/2" T. ROD wt	→	
6 NUT HANDLE wt	→	
TANK (H) Press	→	1180 Psi
O TANK PRESS	→	594 Psi

LOADTO RADIUS ANALYSIS



TIP LINE 6.29 m

$R = \cos\theta \, (10.2)$

L = TIPPING LOAD

4 MASS THROUGH CENTER [SKITTER] 717 Kg = (7034 N)
a BOOM WT. 100 lb = (445 N)

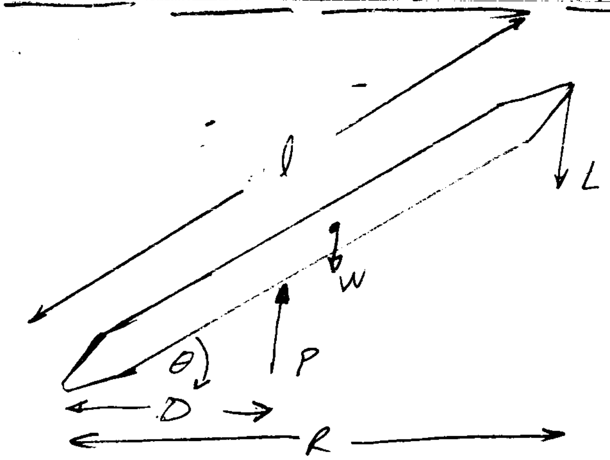
$$L\,[R - 6.29] + 445\,[R/2 - 6.29] = 7034(6.29)$$

$$L = \frac{44244 - 445\,[R/2 - 6.29]}{R - 6.29}$$

$L =$

θ (°)	R (M)	L (N)	L (lb)
20	9.53	13650	3067
25	9.24	14746	3313
30	8.81	17224 N	3870
35	8.33	22152	4980
40	7.79	30206	6790
45	7.19	50442	11346
50	6.54	134082	30130
51°	6.29	—	—

LOAD TO RADIUS ANALYSIS



$l = 10.17\ m$
$W = 800\ lb = 3558\ N$
$D = 1.6\ m$
$P_{cr} = 82{,}000\ lb / Act.$
$= 364{,}730\ N$

$\cos\theta = R/l$

$R = l \cos\theta$

$$L(R) + W(\cos\theta)\, l/2 - P D = \Sigma M = 0$$

$$PD = L\, l \cos\theta + \frac{W \cos\theta\, l}{2}$$

$$PD = l \cos\theta \left[L + \frac{W}{2} \right]$$

$$\frac{PD}{l} = \cos\theta \left[L + W/2 \right]$$

$$\frac{57382\ N}{\cos\theta} - 1780 = L$$

* SET θ & DETERMINE L

θ	R (M)	L (N)
20°	9.56	59284
25°	9.22	61534
30°	8.81	64479
35°	8.33	68270
40°	7.79	73127
45°	7.19	79370
50°	6.54	87490
52°	6.26	91423 N

2▷ w/ ACTUATOR
BUCKLING AS
LIMITING FACTOR

```
*****************************************************************************
*                                                                           *
*                     GEORGIA INSTITUTE OF TECHNOLOGY                       *
*                INTEGRATED  COMPUTER  ENGINEERING  SYSTEM                  *
*                                                                           *
*               GTICES 2.8A - GEORGIA TECH PROPRIETARY PRODUCT              *
*                      GENERATED   83/04/08. 13.24.50.                      *
*                                                                           *
*                            DATE : 87/08/01.                               *
*                                                                           *
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GTICES,I=NTRUSS,L=OUT,PL=999999,DP=KC,BF=4,PD=8,LT=58,S1=SDATA.
STRUDL

*** G T S T R U D L *** JULY 1985 *** 85.05-1292
OWNED BY AND PROPRIETARY TO THE GEORGIA TECH RESEARCH CORPORATION

**** ACTIVE UNITS -	LENGTH	WEIGHT	ANGLE	TEMPERATURE	TIME
**** ASSUMED TO BE	INCH	POUND	RADIAN	FAHRENHEIT	SECOND

TYPE SPACE TRUSS
UNIT METER
UNITS DEGREES
GENERATE 11 JOINTS ID 2,3 X 0.0 0.0 Y .667 0.9 Z .866 0.0

/------- CARTESIAN COORDINATES FREE, GLOBAL -------/

JOINT	X	Y	Z
2	0.000	.667	.866
5	0.000	1.567	.866
8	0.000	2.467	.866
11	0.000	3.367	.866
14	0.000	4.267	.866
17	0.000	5.167	.866
20	0.000	6.067	.866
23	0.000	6.967	.866
26	0.000	7.867	.866
29	0.000	8.767	.866
32	0.000	9.667	.866

GENERATE 11 JOINTS ID 3,3 X .5 0.0 Y .667 0.9 Z 0.0 0.0

/------- CARTESIAN COORDINATES FREE, GLOBAL -------/

JOINT	X	Y	Z
3	.500	.667	0.000
6	.500	1.567	0.000
9	.500	2.467	0.000
12	.500	3.367	0.000
15	.500	4.267	0.000
18	.500	5.167	0.000
21	.500	6.067	0.000
24	.500	6.967	0.000
27	.500	7.867	0.000
30	.500	8.767	0.000
33	.500	9.667	0.000

GENERATE 11 JOINTS ID 4,3 X -.5 0.0 Y .667 0.9 Z 0.0 0.0

/------- CARTESIAN COORDINATES FREE, GLOBAL -------/

JOINT	X	Y	Z
4	-.500	.667	0.000
7	-.500	1.567	0.000
10	-.500	2.467	0.000

13	-.500	3.367	0.000
16	-.500	4.267	0.000
19	-.500	5.167	0.000
22	-.500	6.067	0.000
25	-.500	6.967	0.000
28	-.500	7.867	0.000
31	-.500	8.767	0.000
34	-.500	9.667	0.000

JOINT COORD
1 0 0 .325 SUPPORT
35 0 10.2 0.1
JOINT COORD SPHERICAL
36 1.6 45. 135. OFFSET 1 SUPPORT
37 1.6 45. 195. OFFSET 1 SUPPORT
MEM INC

1	1	2
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3	1	4
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6	4	2
7	2	5
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88    24    26
89    25    27
90    23    28
91    27    29
92    28    30
93    26    31
94    30    32
95    31    33
96    29    34
97    32    35
98    33    35
```



```
99    34    35
TYPE SPACE FRAME
MEM INC
100   36    10
101   37    9
UNITS METER KGS
CONSTANTS
E 100.E9
G 37.5E9
DENSITY 1.45E3
UNIT MM
MEM PROP
1 7 11 13 14 15 19 20 21 25 27 AX  8000.
2 TO 99  AX 5000.
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 7        - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 11       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 13       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 14       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 15       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 19       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 20       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 21       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 25       - DATA IGNORED
**** STRUDL WARNING 1.612 - PROPERTIES PREVIOUSLY SPECIFIED FOR MEMBER 27       - DATA IGNORED
100 101 IY 20000. IZ 20000. AX 8000. IX 20000.
 PRINT MEMBER LENGTH MEMBER 100 101
```

```
****************************************
*  PROBLEM DATA FROM INTERNAL STORAGE  *
****************************************

JOB ID - NONE          JOB TITLE - NONE GIVEN

ACTIVE UNITS -  LENGTH        WEIGHT         ANGLE        TEMPERATURE       TIME
                  MM            KG             DEG            DEGF            SEC
MEMBER                       LENGTH------/

MEMBER                       LOCAL COORD.

100                            1923.416
101                            1732.633

****************************************
*  END OF DATA FROM  INTERNAL STORAGE  *
****************************************
```



```
UNITS POUNDS
LOADING 1 'LINE TENSION'
JOINT LOAD
35 FORCE Z -2828.
35 FORCE Y -2828.
  STIFFNESS ANALYSIS

BANDWIDTH INFORMATION BEFORE RENUMBERING.

THE MAXIMUM BANDWIDTH IS    23 AND OCCURS AT JOINT 7
THE AVERAGE BANDWIDTH IS                        11.941
THE STANDARD DEVIATION OF THE BANDWIDTH IS       9.068
                                            ----------
                                                21.009
                                            **********

BANDWIDTH INFORMATION AFTER  RENUMBERING.

THE MAXIMUM BANDWIDTH IS     4 AND OCCURS AT JOINT 5
THE AVERAGE BANDWIDTH IS                         3.412
THE STANDARD DEVIATION OF THE BANDWIDTH IS        .911
                                            ----------
                                                 4.323
                                            **********

THE PSEUDO-DIAMETER OF THE STRUCTURE IS   12 BETWEEN JOINTS 35       AND 2

TIME FOR CONSISTENCY CHECKS FOR  101 MEMBERS       .10 SECONDS
TIME FOR BANDWIDTH REDUCTION                       .18 SECONDS
TIME TO GENERATE  101 ELEMENT STIF. MATRICES       .15 SECONDS
TIME TO ASSEMBLE THE STIFFNESS MATRIX              .32 SECONDS
TIME TO PROCESS    37 JOINTS                       .01 SECONDS
TIME TO SOLVE WITH    17 PARTITIONS                .13 SECONDS
TIME TO PROCESS     37 JOINT DISPLACEMENTS         .02 SECONDS
TIME TO PROCESS  101 ELEMENT DISTORTIONS           .39 SECONDS
TIME FOR STATICS CHECK                             .03 SECONDS
  LIST FORCES MEMBERS 1 TO 101
```

****
RESULTS OF LATEST ANALYSES
****

PROBLEM - NONE TITLE - NONE GIVEN

ACTIVE UNITS MM LB DEG DEGF SEC

--- LOADING - 1 LINE TENSION ---

MEMBER FORCES

MEMBER	JOINT	FORCE AXIAL	FORCE SHEAR Y	FORCE SHEAR Z	MOMENT TORSIONAL	MOMENT BENDING Y	MOMENT BENDING Z
1	2	14134.9470559					
2	3	3072.4215420					
3	4	2965.6939443					
4	3	-5140.8198641					
5	4	-1072.6195564					
6	2	-1244.0191809					
7	5	14485.0757422					
8	6	-1176.5258971					
9	7	2177.5709013					
10	6	-3852.1186254					
11	7	-37.1900744					
12	5	3898.8008959					
13	8	21459.2585748					
14	9	-4610.0378719					
15	10	-1363.0979454					
16	9	-3852.1186381					
17	10	9984.6571311					
18	8	-1632.7584733					
19	11	23456.7246782					
20	12	-12407.6052997					
21	13	-13877.1194920					
22	12	1632.7585485					
23	13	-.0000955					
24	11	-1632.7584637					
25	14	20617.6947316					

26	15	-10938.0902044					
27	16	-12407.6045980					
28	15	1632.7585083					
29	16	-.0001146					
30	14	-1632.7585019					
31	17	17578.6647336					
32	18	-9468.5751077					
33	19	-10938.0897375					
34	18	1632.7585242					
35	19	-.0000784					
36	17	-1632.7585019					
37	20	14639.6347847					
38	21	-7999.0600163					
39	22	-9468.5747611					
40	21	1632.7585242					
41	22	-.0000255					
42	20	-1632.7585115					
43	23	11700.6047752					
44	24	-6529.5450186					
45	25	-7999.0598218					
46	24	1632.7585147					
47	25	-.0000127					
48	23	-1632.7584988					
49	26	8761.5748565					
50	27	-5060.0300158					
51	28	-6529.5448435					
52	27	1632.7585401					
53	28	-.0000509					
54	26	-1632.7585308					
55	29	5822.5449153					
56	30	-3590.5150038					
57	31	-5060.0298883					
58	30	1632.7585592					
59	31	-.0001019					
60	29	-1632.7585115					
61	32	2883.5149903					
62	33	-2120.9999690					
63	34	-3590.5149136					
64	33	459.5005373					
65	34	1759.9256846					
66	32	-1173.2579678					
67	5	5182.5466102					
68	6	50.0341205					
69	7	-5242.6607811					
70	8	5182.5466149					
71	9	50.0341051					
72	10	-5242.6607834					
73	11	-2196.6735606					
74	12	.0001258					
75	13	2196.6734673					
76	14	-2196.6735630					
77	15	.0000982					
78	16	2196.6734778					
79	17	-2196.6735914					
80	18	.0000911					
81	19	2196.6735612					
82	20	-2196.6735748					

83	21	.0000186					
84	22	2196.6735015					
85	23	-2196.6735133					
86	24	-.0000083					
87	25	2196.6735606					
88	26	-2196.6735086					
89	27	.0000118					
90	28	2196.6735228					
91	29	-2196.6735583					
92	30	-.0000189					
93	31	2196.6735110					
94	32	-2196.6735748					
95	33	-.0000284					
96	34	2196.6734802					
97	35	2475.6892887					
98	36	-2935.2725696					
99	35	-2935.2725717					
100	36	12316.7180665	630.9738286	-2020.0710155	-.0000000	3885437.4892657	1213625.3408729
100	10	-12316.7180665	-630.9738286	2020.0710155	.0000000	.0000001	-.0000001
101	37	12605.3570312	-653.8444383	-1652.0428425	-.0000000	2862384.0545514	-1132872.4934444
101	9	-12605.3570312	653.8444383	1652.0428425	.0000000	-.0000000	.0000001

LIST REACTIONS JOINTS 1 TO 37

```
****************************
*RESULTS OF LATEST ANALYSES*
****************************
```

PROBLEM - NONE TITLE - NONE GIVEN

ACTIVE UNITS MM LB DEG DEGF SEC

--- LOADING - 1 LINE TENSION ---

RESULTANT JOINT LOADS SUPPORTS

JOINT		FORCE X FORCE	FORCE Y FORCE	FORCE Z FORCE	MOMENT X MOMENT	MOMENT Y MOMENT	MOMENT Z MOMENT
1	GLOBAL	-59.5316160	-15479.3770564	-8710.7117876			
36	GLOBAL	-7219.8168713	9006.8236395	4788.7035830	2117890.8411980	2795901.6180392	-2065872.8596090
37	GLOBAL	7279.3482852	9300.5534917	4750.0081343	-796904.6569102	1823328.5663641	-2348841.9398818


```
$ PLOT DEVICE SCOPE 4014 B 120
$ PLOT PROJ X 0    Y 0    Z 0
$ R Y -30
$ R Y -30
$ R Y -30
$ R Y -15
$ R X -15
$ R X -15
$ R X -30
$ L L 1
$ END
  STEEL TAKE OFF
```

```
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
<                                                                                >
<  ACTIVE UNITS      WEIGHT  LB         LENGTH  MM                               >
<                                                                                >
<  TOTAL LENGTH, WEIGHT AND VOLUME FOR SPECIFED MEMBERS                          >
<                                                                                >
<  LENGTH =    1.0907E+06   WEIGHT =    1.8739E+03   VOLUME =    5.8621E+08      >
<                                                                                >
<                                                                                >
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
```

FINISH

DYNAMIC AREA SUMMARY STATISTICS.

```
INITIAL POOL SIZE                        3550
POOL SIZE INCREMENT                      3550
NUMBER OF DATA POOL MOVES                 120
DATA COMPACTIONS                            4
LOW RELEASED                                0
HIGH RELEASED                               0
LOW UNRELEASED                              0
LOW MODULES                                 1
HIGH MODULES                                0

BLOCKS READ FROM DISK                      90
BLOCKS READ FROM ECS                        2
SEQUENTIAL READ-AHEADS INITIATED            0
BLOCKS READ AHEAD DISCARDED                 0
ONE-PRU READ COUNT                          0
ONE-PRU WRITE COUNT                         3
BLOCKS WRITTEN TO DISK                      0
ONE-WORD UPDATES IN ECS                     0
BLOCKS REWRITTEN TO ECS                     0

MAXIMUM NUMBER OF ALLOCATED WORDS      230774
MAXIMUM FIELD LENGTH ATTAINED          277200
NUMBER OF CRASHES                          28
NUMBER OF FIELD LENGTH INCREASES           27
NUMBER OF FIELD LENGTH DECREASES            3
NUMBER OF OVERFLOW-ACTION CALLS             3

**** SYSTEM RESOURCE:      39.860 UNITS.
**** CPU TIME:              3.798 SECONDS.
**** MASS STORAGE:          3.561 K-UNITS + ANY OVERFLOW.
```

APPENDIX 3

DESIGN ALTERNATIVES

Many alternatives to the final lifter design were considered during the design process. Twelve different types of lifting implements, each with many possible variations, were discussed and eventually eliminated in favor of the Gin-Pole type crane. After this type of lifter was chosen, the boom design was considered. The most important alternatives to the type chosen were the solid, telescoping boom, and the square cross-section truss. The telescoping boom was abandoned because of the inability to adjust the boom length under load conditions. The square truss, after analysis, proved to provide less load-carrying capacity for a given weight than the triangular truss.

Several methods of manipulating the boom were discussed. Included were hoist and mast systems, rotating bases, and the actuator system. It was concluded that the actuators are the easiest to control and provide the greatest stability for the system at all positions. Hydraulic, pneumatic, and mechanical actuators were discussed, with the mechanical power screw design chosen for its ease of control and simplicity.

There were two possible positions for the electric hoist to be mounted: at the base of the boom and at the top end of the boom. By mounting the hoist at the top of the boom, the compression caused by the cable at the roller could be eliminated. The trade-off in doing this is that the truss and actuators must then support the weight of the electric hoist. It was determined that the most efficient system would be with the hoist mounted on a platform at the base of the boom. Also, a multiple sheath block and tackle system was considered to reduce the load on the drum of the hoist. However, it was found that the additional weight from the sheathes is greater than the weight saved by using a lighter hoist.

Other power systems considered include nuclear power, rechargable batteries, photovoltaics, thermal gradient systems, and gas turbines. The gas turbine could be made more efficient on the moon because of the natural vacuum.

APPENDIX 4

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty BB
Jim Clark JC
Sharon Jadrnak SMJ
Kipp Kiger KK
Mike Rupert MR
Paul Stanley PRS
R. K. Whitehead, Team Leader RKW

DATE: April 9, 1987

RE: LUNAR CRANE -- Progress Report #1

PROBLEM STATEMENT (draft): To design a crane which will be transported to and operate on the lunar surface. This crane is needed to load and unload any lunar transport vehicle, lunar base modules, and various supplies and cargo which will be needed at the lunar base. It will also aid in the construction of the lunar base.

Since our initial meeting on April 2, the group has met on three separate occasions. We have researched crane designs (library and field trip), brainstormed and discussed several design approaches, and discussed performance objectives and constraints for the crane. Sketches are included of two designs that we are considering.

On April 6, we made a conference call to Sam Ximinez at the University of Houston to discuss the lunar modules. The facts we gathered from him are:

- -- module weight will be approx. 40,000 earth lbs.
- -- module dimensions are 20 ft. dia. by 50 ft. long
- -- to remove the modules from the lander, the crane will need to lift the module 40 ft.
- -- one module, the control tower, will stand on its end on top of a 20 ft. high node, and the crane will have to perform this operation

Some of the issues which will be further researched and discussed are structural design, power systems, lighting, materials, lubricants, and cooling-shielding. Constraints to be considered include weight, dependability, simplicity, lunar gravity, extreme temperatures, abrasive dust, heat transfer, and a vacuum environment.

FIG 1

CRANE

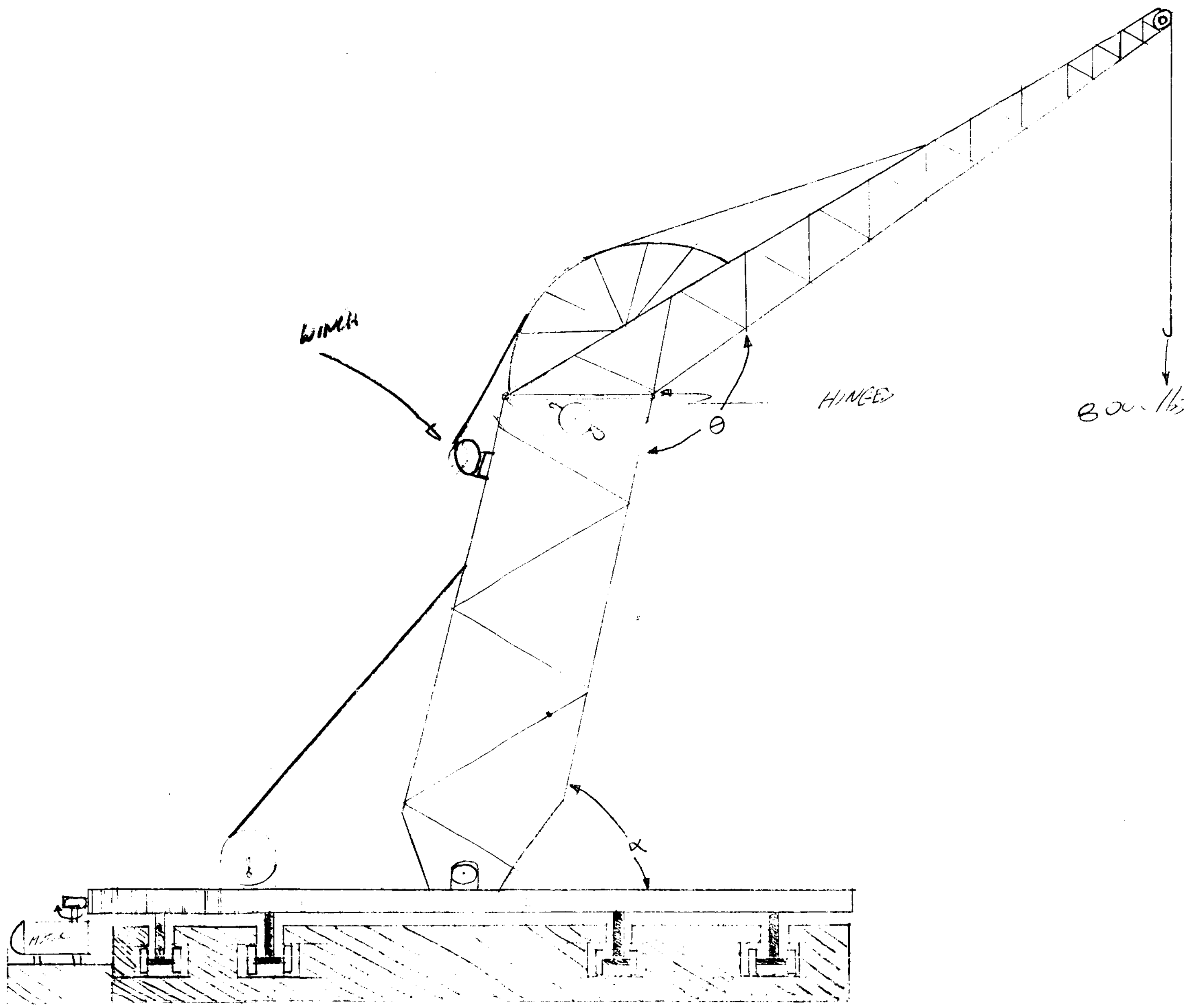
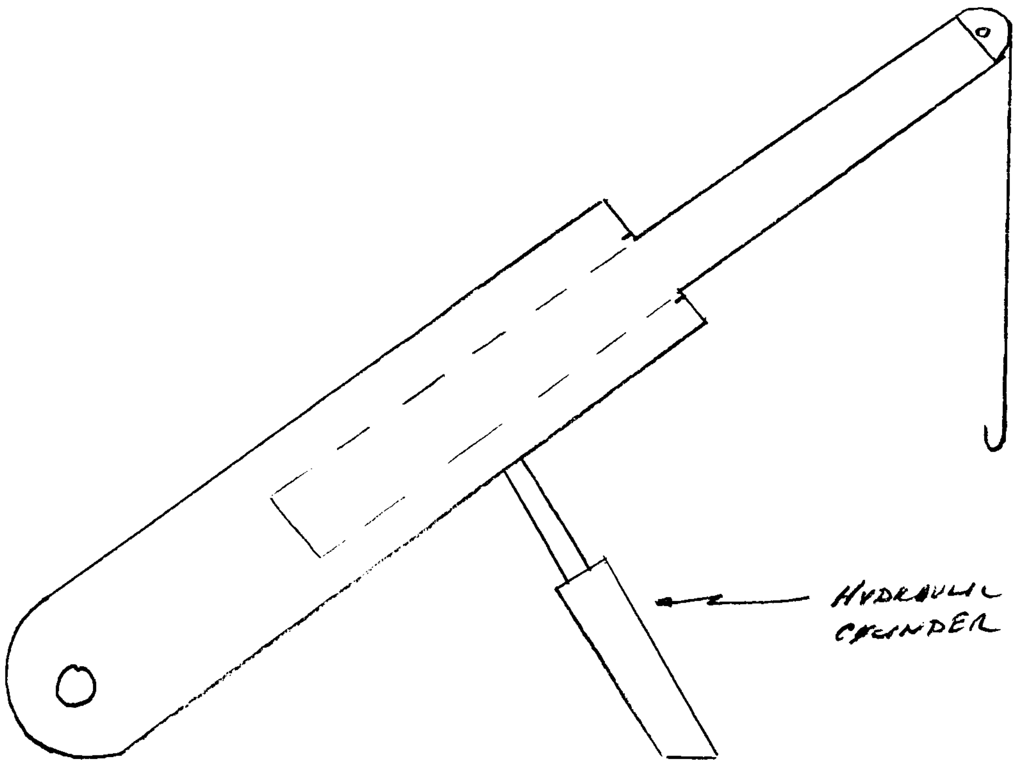
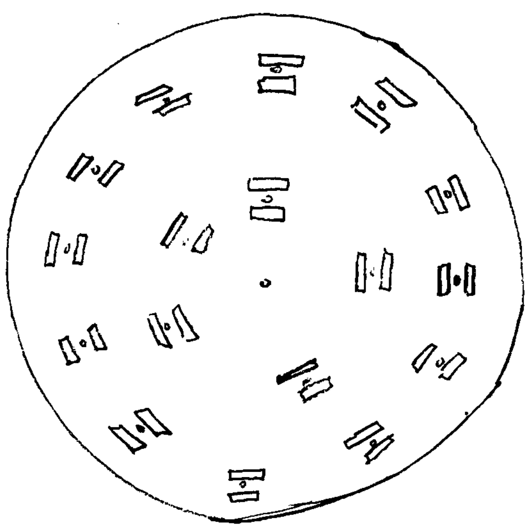


FIG. 2



BASE AS SHOWN IN FIG 1.



TOP VIEW OF BASE

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty
Jim Clark
Sharon Jadrnak
Kipp Kiger
Mike Rupert
Paul Stanley
R. K. Whitehead, Team Leader

DATE: April 16, 1987

RE: LUNAR CRANE -- Progress Report #2

The team has met three times since the last progress report. Several tasks were assigned to various group members, and the following is a compilation of the individual efforts:

Kipp and Jim - Researched crane designs and decided on a suitable style. Took field pictures of several hydraulic cranes and talked with crane operators. Arranged for literature on several cranes to be sent to us.

Brian and Mike - Researched different materials for crane truss construction. Titanium alloy appeared to have the best characteristics (density, strength, expansion coefficients, etc.) without taking into consideration costs.

R.K. and Sharon - Brainstormed and consequently established design criteria and performance objectives. Compiled information for the Problem Statement.

Paul - Contacted and conferred with several students and professionals who had access to GTSTRUDEL. Obtained information on its use and limitations along with its required input for any kind of truss analysis.

Attached is our final draft of the Problem Statement and our weekly graphic.

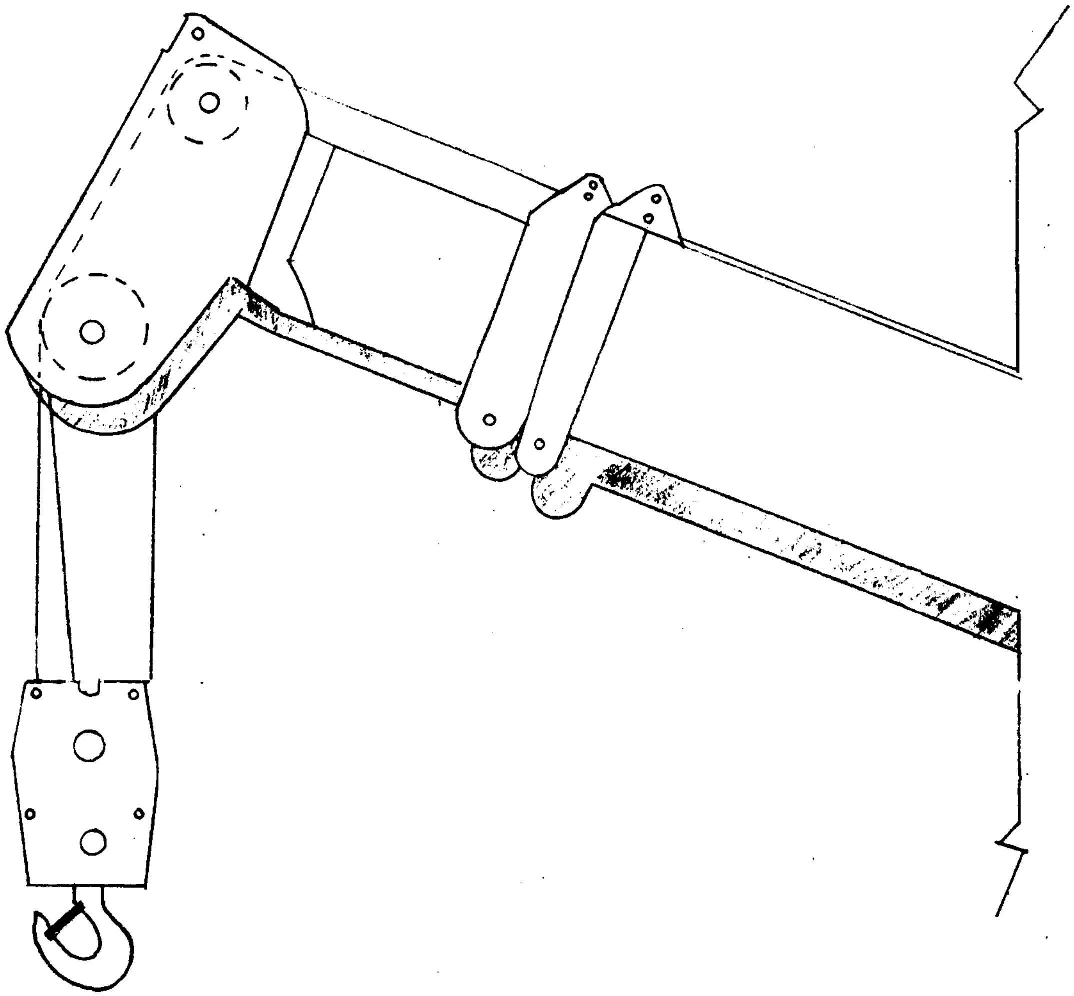
Titanium Alloy for Lunar Crane

ALLOY: Ti-6Al-4V

PHYSICAL PROPERTIES		
Density, lb/cu. in.	0.160	
Melting Temp, F	3000	
Thermal Conductivity BTU/hr/sp ft/degF/ft	4.2	
Coeffficient of Therm. Exp. (RT-1000F) per degF x EE -6	5.3	
Specific Heat, BTU/lb/degF	0.135	
Elec Resis, microhm-cm	177	
Magnetic Prm (20 oersteds)	1.00005	
MECHANICAL PROPERTIES		
Mod of Elast in Tension, 1 EE 6 psi		
Room Temp	16.5	
600 F	13.5	
Shear Mod, 1 EE 6 psi	6.1	
Tensile Strength, 1000 psi		
Room Temp	150	(170 aged)
800 F	90	(130 aged)
Yield Strength, 1000 psi		
Room Temp	128	(155 aged)
800 F	75	(100 aged)
Elongation (in 2 in.), %		
Room Temp	10	(8 aged)
800 F	18	(8 aged)
Compressive Yield Strength, 1000 psi		
Room Temp	-----	
800 F	-----	
FABRICATING PROPERTIES		
Annealing Temp, F	1300-1500	
Stress Relieving Temp, F	900-1200	
Solution Tmep, F	1550-1750	
Aging Temp, F	900-1000	
Forging Temp, F	1400-1900	
Formability	3T-5T	Min. Bend-To-Thickness Ratio (T) for sheet
Weldability	Weldable	

AVAILABLE FORMS

Billet, Bar, Plate, Sheet, Strip, Wire, Extrusions



3 SECTION BOOM END WITH

HOOK BLOCK

FIG. 1

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty
Jim Clark
Sharon Jadrnak
Kipp Kiger
Mike Rupert
Paul Stanley
R. K. Whitehead, Team Leader

DATE: April 23, 1987

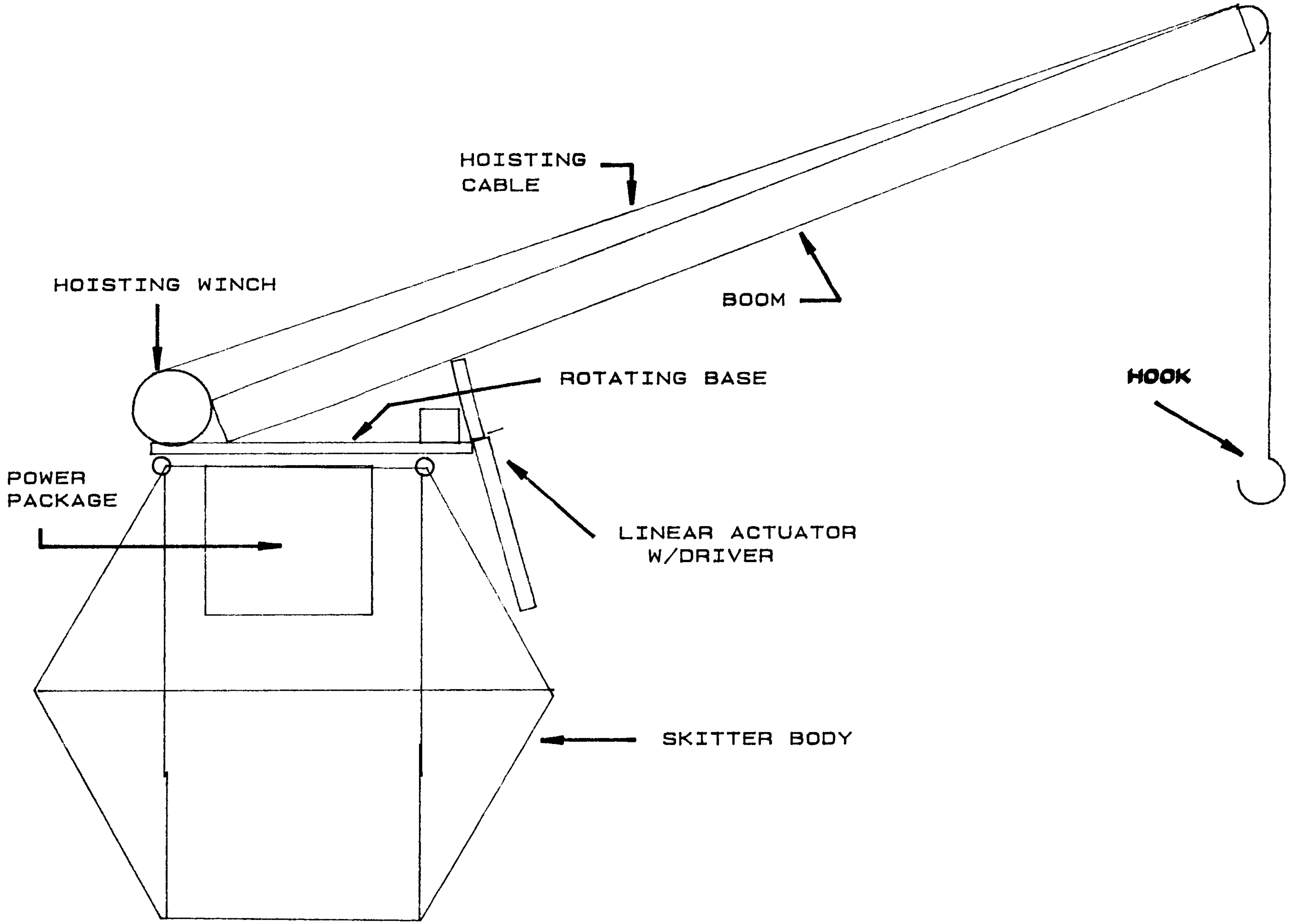
RE: LUNAR CRANE -- Progress Report #3

The group has met twice since the last report. We held a brainstorming session to generate different crane designs, and the results are as follows:

Types of Configurations
Gin Pole - simple construction, very few moving parts, easy to maintain, easily adapted to a pully system.
A-Frame - see bipod, hard to adapt to skitter
Telescoping Boom - versatile, hard to lubricate, many moving parts
Ferris Wheel - complicated, heavy, many parts, good mobility
Folding Truss - 3 winches, too complicated
Mast System - something similar must be incorporated into any boom design, double amount of truss members
Bi-Pod - simple, easy to maintain, lightweight
Mono-Pod - problems same as t-type
Tripod - no mobility
Fork Lift - lack of versatility
T-Type - needs couterweight
Fishing Pole - simple construction, poor stability

Types of Construction
Truss - solid bars or tubes
box, triangular, octagon, other geometries
Solid Members - rectangular, triangular, circular
I-beam - A frame

Attached is the weekly graphic. Individual efforts for the week are as follows:
Brian - Performed preliminary static analysis on winch/mast system and began to research vendor data on hydraulics.
Jim - Became familiar with the CAD systems and researched hydraulics.
Sharon - Began to research vendor data of hydraulics and composed weekly progress report.
Kipp - Attended the on-line data search session and researched hydraulics.
Mike - Researched hydraulics as they apply to the vertical movement of the crane mast.
Paul - Researched lightweight control arms, tubular structures, and software for a lightweight arm.
R. K. - Performed preliminary static analysis on gin-pole/hydraulic system.


HOISTING CABLE
HOISTING WINCH
BOOM
ROTATING BASE
HOOK
POWER PACKAGE
LINEAR ACTUATOR W/DRIVER
SKITTER BODY

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty
Jim Clark
Sharon Jadrnak
Kipp Kiger
Mike Rupert
Paul Stanley
R. K. Whitehead, Team Leader

DATE: April 29, 1987

RE: LUNAR LIFTING IMPLEMENT -- Progress Report #4

Since the last report, the group has met twice and each member has researched a different design topic. At our second meeting, we prepared the mid-term presentation.

Individual effort is as follows:

Brian - Investigated possible clutch systems to provide boom and winch motion from the power system.

Jim - Investigated possible power systems.

Sharon - Investigated possible composite materials for the boom and presented the mid-term report.

Kipp - Investigated possible boom configurations.

Mike - Investigated different winches and pulley configurations.

Paul - Investigated various wire ropes and prepared viewgraphs for the mid-term presentation.

R. K. - Investigated mechanical linear actuators and possible configurations for the actuators on the platform.

Lunar Lifting Implement

ME 4182

Spring 1987

Brian Beatty

Jim Clark

Sharon Jadrnak

Kipp Kiger

Mike Rupert

Paul Stanley

R. K. Whitehead

Mid–term Presentation

April 30, 1987

PROBLEM STATEMENT

To load and/or unload lunar modules, equipment, and various supplies from lunar transport vehicles at the lunar surface, and to aid in the construction of the first phase of the lunar base by lifting modules and materials.

PERFORMANCE CRITERIA

Degrees rotation angle

Lunar lbs. max lifting load

Degrees boom inclination angle

ft/s rotation rate

ft/s hoisting rate

ft/s radial positioning rate

PERFORMANCE OBJECTIVES

- Internal power source
- Remote controlled
- Operate during day and night
- Operate during first ten years of base operations
- Special techniques for large loads
- Loads will be lifted and placed onto transporters
- Remove and store on a frame

DESIGN CONSTRAINTS

Main concern is lunar environment

DESIGN AREAS TO INVESTIGATE

Power System

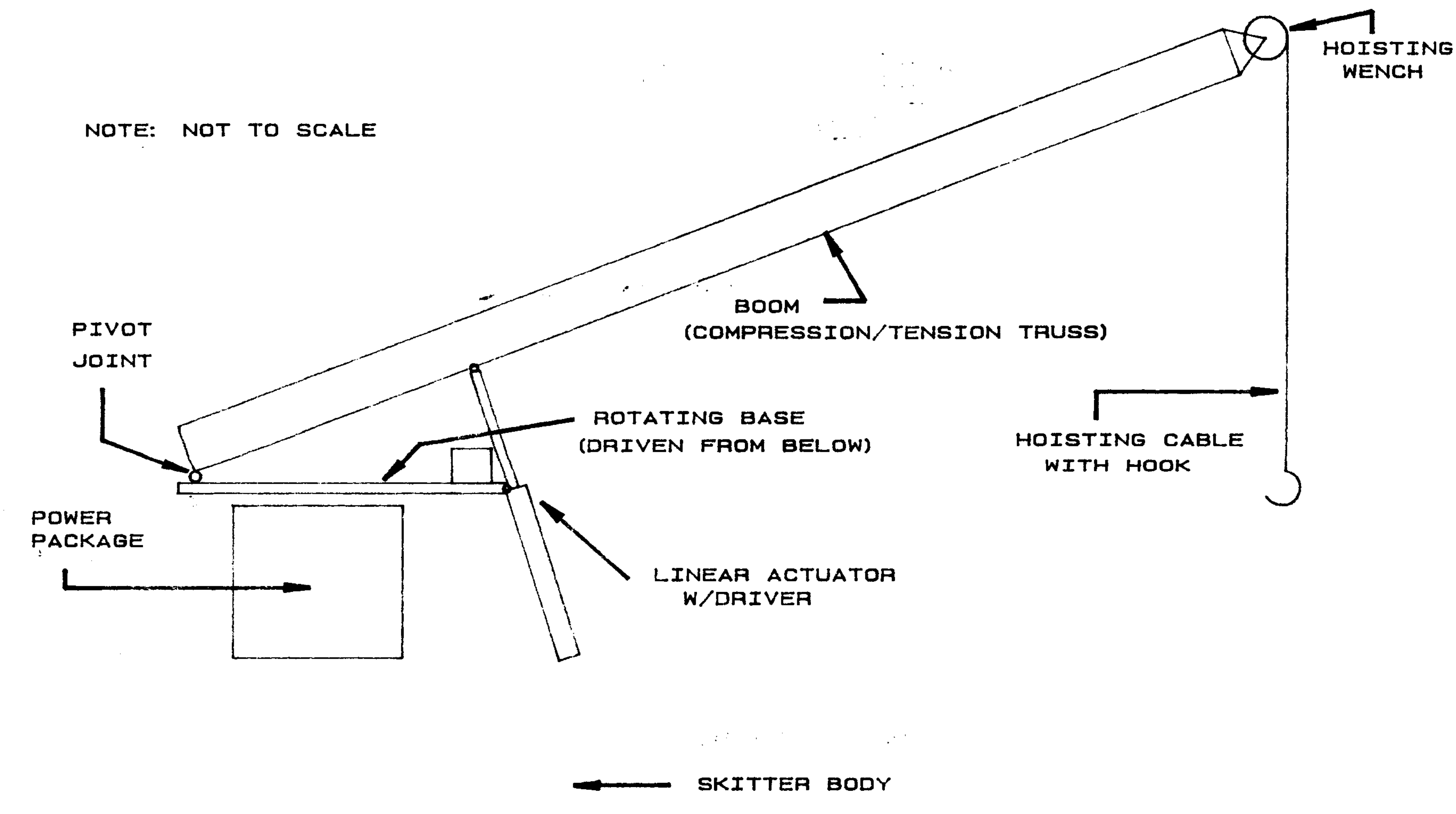
Winch and pulleys

Mechanical linear actuators

Boom design

Materials

Wire rope



GROUP #3
LUNAR LIFTING IMPLEMENT

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty BB
Jim Clark JC
Sharon Jadrnak
Kipp Kiger KK
Mike Rupert MR
Paul Stanley PS
R. K. Whitehead, Team Leader RKW

DATE: May 7, 1987

RE: LUNAR LIFTING IMPLEMENT -- Progress Report #5

Since the last report, the group has met twice and individually researched various design aspects of the lifting implement. After building a model, we have decided to use a two-actuator system for motion of the boom. The boom will be mounted at one corner of the triangular base, and the actuators will be mounted on the sides adjacent to this corner. The boom will be a triangular truss and will most likely be made of a graphite/polyimide composite. Kevlar rope, with an aluminum sheathing for radiation protection, will be used with a winch and pulley system for raising loads. We are still investigating power systems and heat transfer.

Individual effort is as follows:

Brian and Mike - Researched vendor catalogs and standards for information on linear actuators.

Jim - Researched space truss structures and made design decisions concerning geometry of boom.

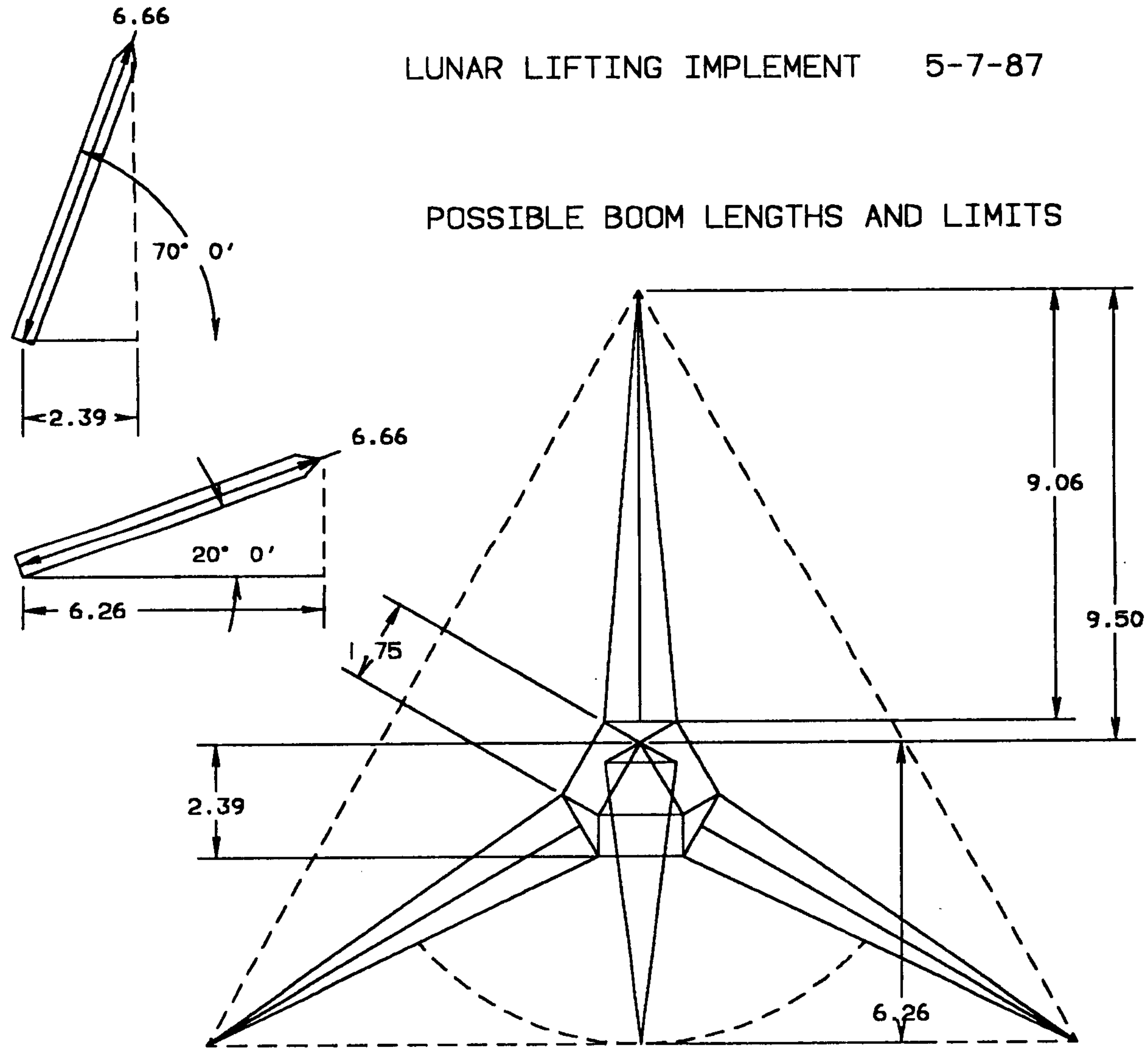
Sharon - Researched information on graphite/polyimide composites and worked with librarian on literature search.

Kipp and R.K. - Built several cardboard models and worked on the statics of the design configuration to help finalized design.

Paul - Researched Kevlar rope properties in the lunar atmosphere and found out that a metal sheathing could be used to protect the rope from radiation.

LUNAR LIFTING IMPLEMENT 5-7-87

POSSIBLE BOOM LENGTHS AND LIMITS



MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
BB Brian Beatty
JC Jim Clark
Sharon Jadrnak
Kipp Kiger
Mike Rupert
Paul Stanley
RKW R. K. Whitehead, Team Leader

DATE: May 14, 1987

RE: LUNAR LIFTING IMPLEMENT -- Progress Report #6

Since the last report, the group has met twice to discuss and make decisions about the particular points of our design. Some of the areas we have discussed include rope, a power source, winches, pulleys, boom design, materials, and controls. A few members of the group will begin the skitter part of our model this week. Our literature search has been performed and has yielded some information on composite materials and truss design.

Individual effort for the week is as follows:

Brian - investigated winches and pulleys.

Jim and Paul - began preliminary design of boom and preliminary GTSTRUDL anaylsis of boom.

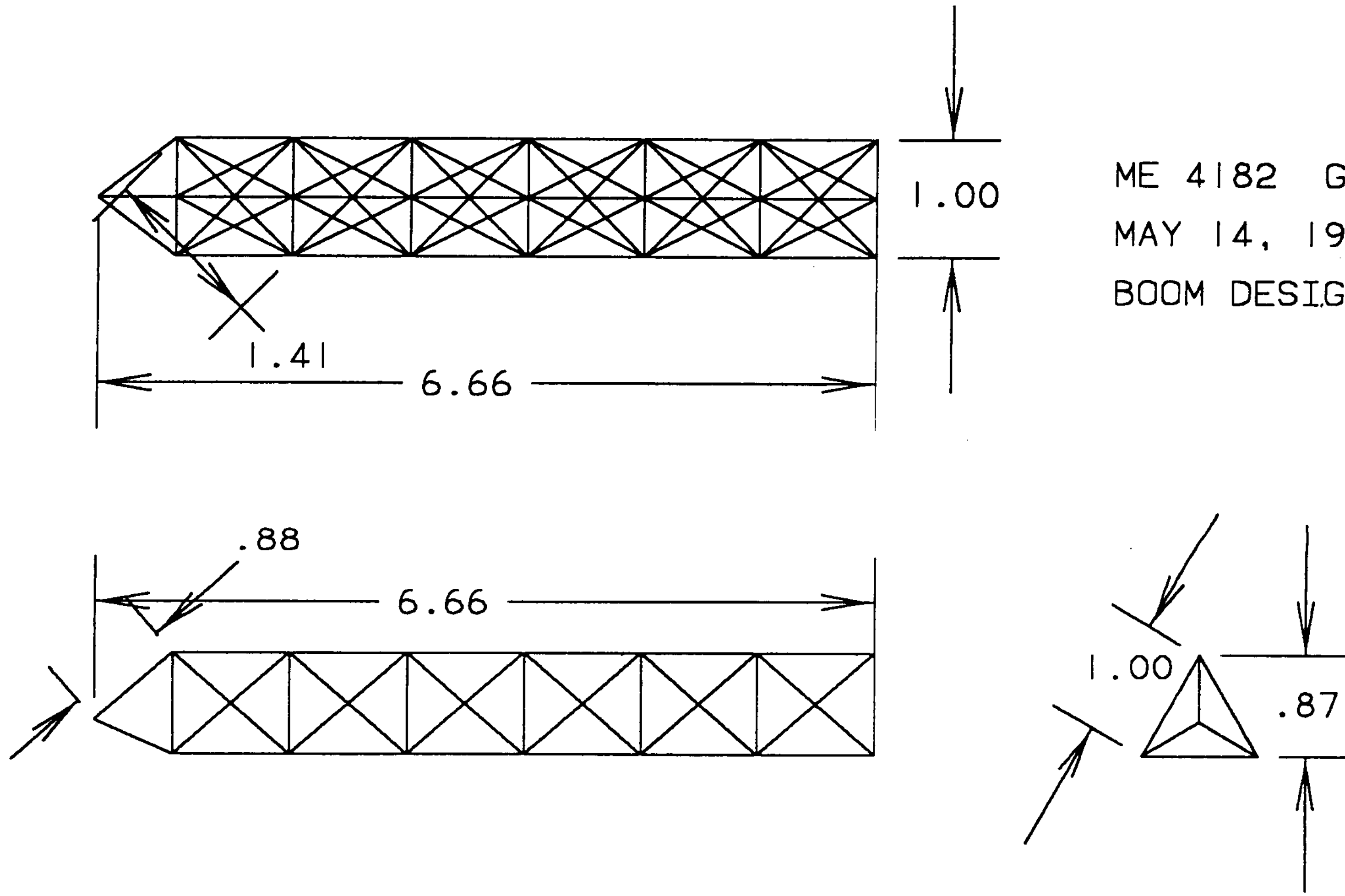
Sharon - coordinated literature search and researched graphite/polyimide materials.

Kipp - began construction of skitter model by purchasing materials and studying existing model.

Mike - investigated the possibility of a pneumatic turbine, which does not seem to be the best source of power

R. K. - investigated universal joints for the base of the boom, ball joints for actuator interface on skitter, and gimbal joints for actuator interface on the boom.

ME 4182 GP 3
MAY 14, 1987
BOOM DESIGN



MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty BB
Jim Clark JC
Sharon Jadrnak
Kipp Kiger
Mike Rupert
Paul Stanley
R. K. Whitehead, Team Leader

DATE: May 14, 1987

RE: LUNAR LIFTING IMPLEMENT -- Progress Report #7

Since the last report, the group has met twice to discuss and refine our design. The skitter model is under construction, and the lifting implement model will be under construction this week. All areas of the design are being investigated or analyzed, and the final report has begun to be written.

Individual effort for the week is as follows:

Brian - Investigated hoist system, power systems, and controls.

Jim & Paul - Continued to work on GTSTRUDL boom model; analysis is underway.

Sharon - Continued to research materials, particularly graphite/polyimides, and outlined the final report.

Kipp - Constructed skitter model and researched universal joints.

Mike - Analyzed fuel cell and platform design.

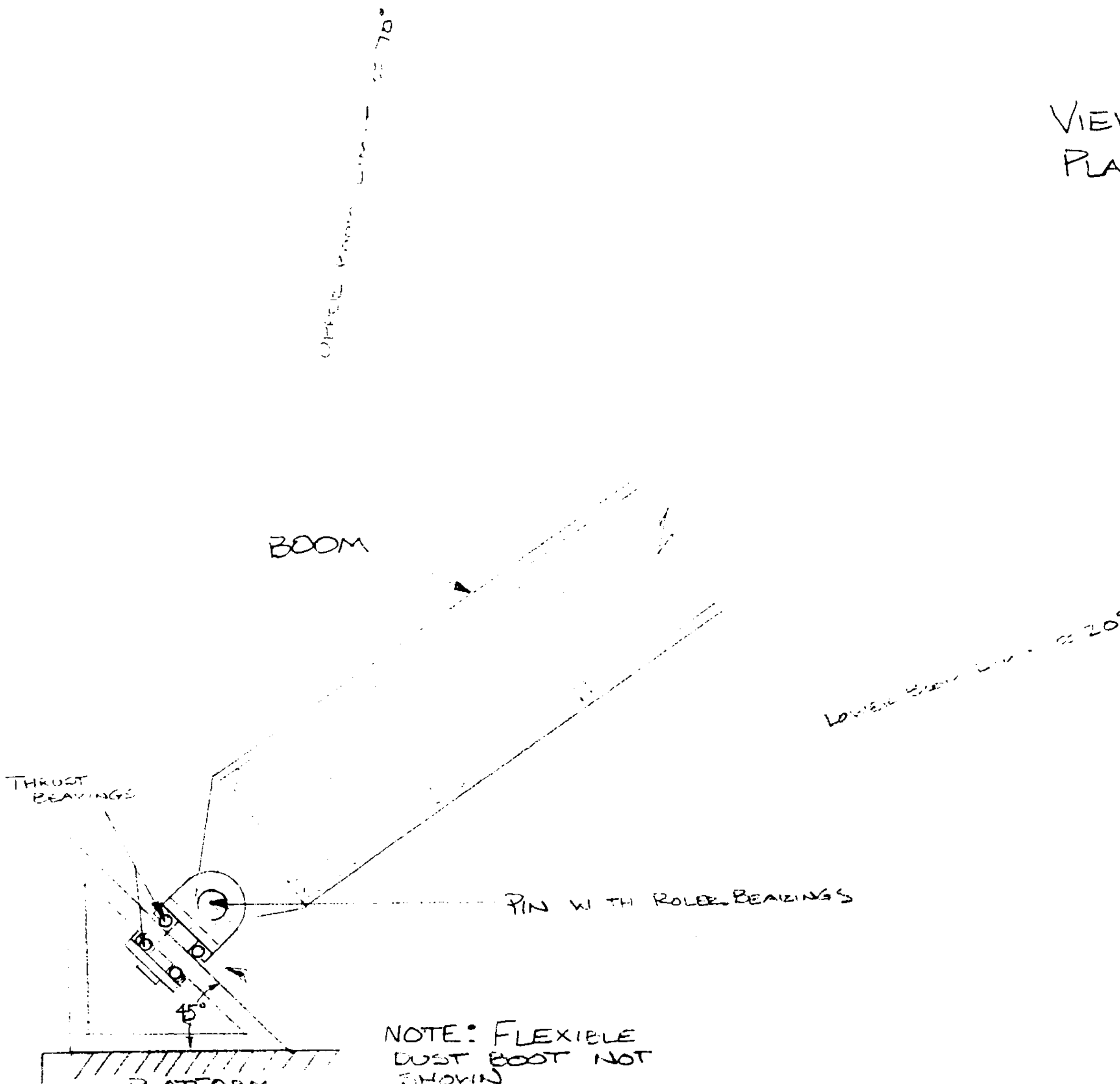
R. K. - Constructed skitter model and researched universal joints.

ME 4182

GROUP # 3

LUNAR LIFTING IMPLEMENT

VIEW OF BOOM – PLATFORM INTERFACE



NOTE: NOT TO SCALE

LUNAR LIFTING IMPLEMENT -- FINAL REPORT OUTLINE
ME 4183 -- GROUP 3

Cover

Title Page

Picture of Project Model

Table of Contents

Abstract

Problem Statement
- Background
- Performance Objectives
- Constraints

Description of Design

Platform	Kipp, R. K.
Boom	Jim, Paul
Actuators	R. K.
Hoist system	Brian
Power supply	Mike, Kipp
Controls	Brian

Analysis

Boom structure	Jim, Paul
Structural forces	Jim, Paul
Materials	Sharon
Hoist system	Brian
Power supply	Mike, Kipp
Controls and operation	Brian
Deployment and storage	Sharon
Weight/mass/inertia/c.g.	

Conclusions and Recommendations

Acknowledgements

References

Appendices
- Appendix 1 -- Drawings
  - overall lifter
  - boom truss
  - platform and interfaces
  - range of motion
  - controls
- Appendix 2 -- Calculations
- Appendix 3 -- Design alternatives
- Appendix 4 -- Progress Reports
- Appendix 5 -- Invention disclosure sheet

MEMORANDUM

TO: Mr. James Brazell

FROM: ME4182 -- Group 3
Brian Beatty BB
Jim Clark JC
Sharon Jadrnak SMJ
Kipp Kiger KK
Mike Rupert MR
Paul Stanley
RKW R. K. Whitehead, Team Leader

DATE: May 28, 1987

RE: LUNAR LIFTING IMPLEMENT -- Progress Report #8

Since the last report, the group has met twice to discuss and refine our design. A rough draft of our report has been prepared for this week. The skitter model is finished, and the lifting implement model is under construction. Each person has been assigned a few sections of the report to finish investigating, analyze, and write up for the report.

Individual effort for the week is as follows:

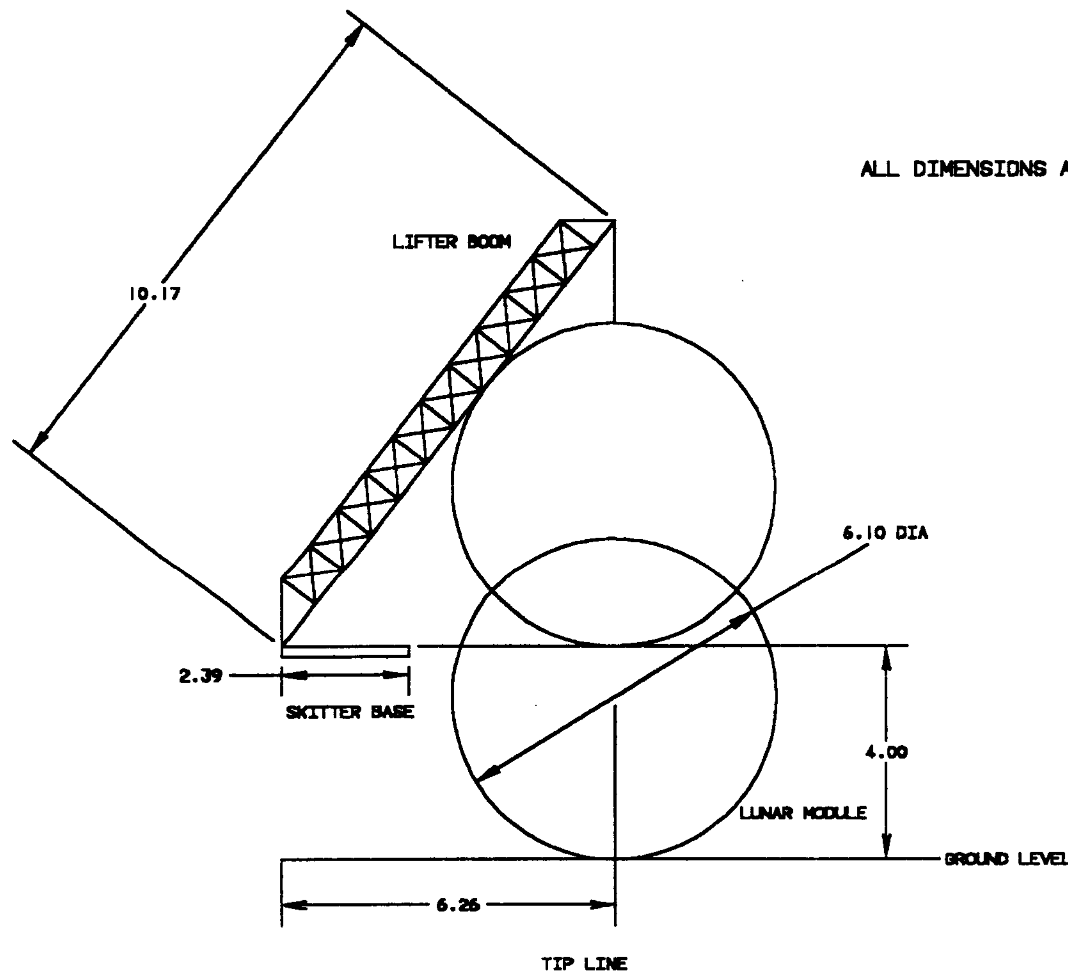
Brian - Investigated hoist system, power systems, and controls. The hoist will most likely be mounted on the platform.

Jim & Paul - Continued to work on GTSTRUDL boom model; analysis is underway. The truss had to be modified and made smaller to avoid twisting.

Sharon - Re-assesed the boom length. Decided on a graphite/polyimde composite for the boom.

Kipp and R.K. - Constructed skitter model and researched universal joints and actuators.

Mike - Investigated and analyzed fuel cells. The space shuttle fuel cells will most likely be the ones used for the lifter.



GEORGIA INSTITUTE OF TECHNOLOGY

LUNAR LIFTING IMPLEMENT
DRAWING: BOOM LENGTH & LIFT CAPABILITY

APPENDIX 5

Disclosure No.____________

GEORGIA INSTITUTE OF TECHNOLOGY

INVENTION DISCLOSURE APPROVAL SHEET

The following questions should be answered by the laboratory or school director, as applicable. The questions are designed to verify the source of the invention and to obtain the viewpoint of other technically qualified scientists as to the uniqueness and efficiency of the invention. This approval MUST be completed before submission of the Invention Disclosure Form to the Office of Technology Transfer.

1. Title of Invention

   Lunar Lifting Device

2. List of Inventor(s)

Brian Beatty	Kipp Kiger
Jim Clark	Mike Rupert
Sharon Jadrnak	Paul Stanley
	R. K. Whitehead

3. Ownership

   In my opinion this invention is:

   __X__ A. Owned by the University in accordance with the Patent Policy.

   _____ B. Was developed by the inventor(s) without use of University time, facilities or materials and is not related to the inventor's area of technical responsibility to the University. Belongs to the inventor(s).

4. Advisor approval for student submissions (if applicable):

____________________________ ________________
Advisor Date

Reviewed for University Ownership by laboratory or school director.

____________________________ ________________
Name Date

____
Title/Unit

Disclosure No.__________

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

Submit this disclosure to the Technology Transfer Office (TTO) or contact the TTO for assistance. Disclosure must contain the following items: (1) title of invention, (2) a complete statement of invention and suggested scope, (3) results demonstrating the concept is valid, (4) variations and alternate forms of the invention, (5) a statement of the novel features of the invention and how these features distinguish your invention from the state of the art as known to you, (6) applications of technology, and (7) supporting information.

1. Title

Technical Title:

Lunar Lifting Implement

Layman's Title (34 Characters):

A Crane for use on the moon

Inventor(s): (Correspondence, patent questions, etc. will be directed to the first named inventor)

A. Signature [signature] Revenue Share% 33 Date__________

Printed Name In Full Sharon (First) M. (Middle) Jadrnak (Last) Citizenship US

Home Address 6714 New Hampshire

City Hammond County Lake State IN Zip Code 46323

Campus Unit/Mail Address Box 36598 Campus Phone 676-0280

B. Signature [signature] Revenue Share% 33 Date__________

Printed Name In Full Brian (First) P. (Middle) Beatty (Last) Citizenship US

Home Address 211 E 55th St

City Savannah County Chatham State GA Zip Code 31405

Campus Unit/Mail Address Box 35579 Campus Phone 892-3257

C. Signature [signature] Revenue Share% 34 Date__________

Printed Name In Full Paul (First) R (Middle) Stanley (Last) Citizenship US

Home Address 10101 Shades Rd

City Huntsville County Madison State AL Zip Code 35803

Campus Unit/Mail Address Box 33981 Campus Phone 676-0200

Disclosure No.___________

(Continuation Page)
DISCLOSURE OF INVENTION

2. Statement of Invention

Give a complete description of the invention. If necessary, use additional pages, drawings, diagrams, etc. Description may be by reference to a separate document (copy of a report, a preprint, grant application, or the like) attached hereto. If so, identify the document positively. The description should include the best mode that you presently contemplate for making (if the invention is an apparatus) or for carrying out (if the invention is a process) your invention.

See report "Lunar Lifting Implement", Georgia Tech: June 1987
NASA/University Advanced Missions Space Design Program

Inventor(s) R.K. Whitehead Date 4/8/87 Witness [signature] Date 4/10/87

____________ Date ________ Witness ____________ Date ____________

____________ Date ________ Witness ____________ Date ____________

Disclosure No.__________

(Continuation Page)
DISCLOSURE OF INVENTION

3. Results demonstrating the concept is valid

Cite specific results to date. Indicate whether you have completed preliminary search studies, laboratory model or, prototype testing.

Basic computer analysis of boom design.
1/10 th scale model built to show feasability of actuator system.

4. Variations and alternative forms of the invention

State all of the alternate forms envisioned to be within the full scope of the Invention. List all potential applications and forms of the Invention, whether currently proven or not. (For example, chemical inventions should consider all derivatives, analogues, etc.) Be speculative in answering this section. Indicate what testing, if any, has been conducted on these alternate forms.

Single actuator, rotating base
Different attachment points for actuators on boom.
Various pulley systems
Different winch
Tapered boom design
Rectangular boom design

Inventor(s) Sharon Jodmok Date 5/6/87 Witness [signature] Date 5/6/87

__________ Date__________ Witness__________ Date__________

__________ Date__________ Witness__________ Date__________

Disclosure No.____________

(Continuation Page)
DISCLOSURE OF INVENTION

5. Novel Features

a. Specify the novel features of your invention. How does the invention differ from present technology?

Two actuators providing both elevation and rotation adjustment
Graphite polymide material used for boom members
Universal joints on actuator nut.

b. What is the deficiency in the present technology which your invention improves upon, or the limitations it overcomes?

Weight/Lifting capacity ratio

c. Have you or an associate searched the patent and/or scientific literature with respect to this invention? Yes______No__✓__. If Yes indicate the literature found which you believe to be pertinent to your invention and enclose copies if available.

d. Indicate any other art, either in the literature or technology used by others, of which you are aware that is pertinent to your invention and enclose copies if available. (Note: An inventor is under duty by law to disclose such art to the U.S. Patent and Trademark Office.)

Inventor(s) P. Stroule Date 4/15/87 Witness [signature] Date 4/15/87

______________ Date__________ Witness____________ Date__________

______________ Date__________ Witness____________ Date__________

Disclosure No.____________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

6. Application of the technology

List all products you envision resulting from this invention, and whether these products could be developed in the near term (less than 2 years) or long term (more than 2 years).

Radio antenna mast

Inventor(s) J. Clark Date 5/13/87 Witness [signature] Date 5/13/87

__________ Date ________ Witness __________ Date ________

__________ Date ________ Witness __________ Date ________

Disclosure No.________________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

1. As there publications-theses, reports, preprints, reprints, etc. pertaining to the invention? Please list with publication dates. Include manuscripts for publications (submitted or not), news releases, feature articles and items from internal publications.

None other than the included report.

2. What was the date the invention was first conceived? April 8, 1987 Is this date documented? no Where?________________ Are laboratory records and data available? Give reference numbers and physical location, but do not enclose.

3. A literature search should be done by the inventor to determine publications relevant to the Invention. Please list and any related patents known to you.

4. Date, place, and circumstances of any disclosure. If disclosed to specific individuals, give names and dates.

5. Was the work that led to the invention sponsored? If yes, check the appropriate blank(s). Government agency ✓, industrial company ____ university____ other____.

Sponsor	Project No.
NASA	

6. What firms do you think may be, or are interested in the invention. Why? Name companies and specific persons if possible.

Disclosure No.________________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

7. Being for the moment the Devil's Advocate, what do you see the greatest obstacle to the adoption of your invention?

Cost/benefit ratio

8. Alternate technology and competition

a. Describe alternate technologies of which you are aware that accomplish the purpose of the invention.

b. List the companies and their products currently on the market which make use of these alternate technologies.

c. List any research groups currently engaged in research and development in this area.

9. Future research plans

a. What additional research is needed to complete development and testing of the invention? What are the time frames and estimated budget needed for completion of each step?

Final design - 6 months, $100k
Prototype - 1 year, $500k

b. Is this research presently being undertaken? Yes_____No__X__Actively pursued? Yes_____No__X__If yes, under whose sponsorship? ____________________
If no, should corporate sponsorship be pursued? Yes_____No__X__.

Disclosure No.________________

(Continuation Page)
DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

10. Was this invention conceived or reduced to practice in the course of an extramurally sponsored project yes___ no X .

a. If yes, has sponsor been notified of this invention yes___ no___.

b. If yes, please provide Georgia Tech project number(s) so that sponsor's rights to this invention may be determined. ________________
____

11. Attach, sign and date additional sheets if necessary. Enclose sketches, drawings, photographs and other materials that help illustrate the description. (Rough artwork, flow sheets, Polaroid photographs and penciled graphs are satisfactory as long as they tell a clear and understandable story.)